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ABSTRACT

The Chernobyl nuclear plant explosion on April 26, 1986, was the world's most serious nuclear power accident to date. This document examines the accident's impact on the world from a variety of perspectives. The first major section of the book provides a step-by-step account of the accident itself, beginning with the special testing that eventually led to the disaster. Included are data on the daily release of radioactivity from Chernobyl from April 25 to May 7, the maximum reported radiation levels in Europe following the accident, and the estimated direct financial losses in the Soviet Union resulting from the incident. The "Political Fallout" section examines public opposition to nuclear power in various countries. It provides a summary of both the citizen responses (such as protests, demonstrations, and petitions) and the political responses that followed the accident. Other sections examine the safety of nuclear power in general and the possible effects of Chernobyl on the once-held vision of a nuclear-powered world. Major adjustments in policy are traced in selected countries since 1980, and examples of governmental decisions to reduce or eliminate nuclear power are discussed. (TW)

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Introduction

When the Chernobyl nuclear plant exploded on April 26, 1986, the resulting conflagration engulfed more than a Soviet reactor. A few days later, much of Europe was experiencing the highest levels of radioactive fallout ever recorded there, and within two weeks, minor radioactivity was detected throughout the northern hemisphere. But the political fallout from Chernobyl will be its lasting legacy. Since the accident the pro-nuclear consensus has collapsed in country after country, and the future of nuclear power, already hanging by a thread in some nations, is now in greater jeopardy than ever.

Chernobyl is the world's most serious nuclear power accident so far. The direct costs include 1,000 immediate injuries, 31 deaths, 135,000 people evacuated from their homes in the Ukraine, and at least $3 billion in financial losses. But the long-term implications are far more troubling and uncertain. It may not be possible simply to "remove the consequences of the accident," as Soviet officials put it. The health of people and of the environment in the Ukraine and throughout Europe could be affected for decades. Estimates of resulting cancer deaths by researchers in the field range from less than 1,000 to almost 500,000.[1]

The author would like to thank Alan Durning for his dedicated and skilled assistance in every aspect of this paper's preparation, and Susan Norris for production and outreach assistance. He would also like to thank John Ahearne, Bob Civiak, Chris Dodge, and Jim MacKenzie for their reviews of the manuscript. This paper is based on meetings with officials and experts in six European countries during August 1986, and attendance at the September 1986 meeting of the International Atomic Energy Agency, in addition to the references cited.

Nuclear power has been controversial for more than a decade, but the Chernobyl accident burned deeply into the psyches of millions of people who had not previously had strong feelings about it. Over 20 European countries received enough fallout to require food restrictions, a dispersion of radioactivity that surprised most scientists. Because radioactivity can be neither seen nor smelled and its effects can be longlasting, people throughout Europe were caught up in a wave of anxiety.

Majority opinion had already turned against nuclear power in many countries, but polls taken after Chernobyl showed support for nuclear expansion at the lowest levels ever. The psychological reaction was heightened because some leaders had misled the public into thinking that a serious nuclear accident was all but impossible. In Europe, government credibility eroded further because many people believe that officials failed to warn them of the health threat from Chernobyl. In the United States, public support of further nuclear development fell from 64 percent in 1975 to 19 percent in 1986.[2]

Rarely have so many countries been so affected by a single event. Chernobyl has tested the ability of East and West to cooperate, the public's confidence in government authorities, and society's faith in technology. And since Chernobyl, nuclear power has become a contentious international issue, particularly for neighboring countries with differing nuclear policies.

Although the leaders of most major countries remain committed to nuclear power, they have had to respond to an aroused public. Some, including Chancellor Helmut Kohl of West Germany, have introduced new nuclear safety programs. The Netherlands, Switzerland, and other countries have indefinitely postponed additional nuclear plants. Opposition political parties in the United Kingdom and other countries that once favored nuclear power have come out strongly against it.

In some nations, debate has begun over whether to close existing reactors. Three countries with nuclear plants have decided to aban-

"Nuclear power's share of world electricity could actually be lower in the year 2000 than it is in 1987."

don nuclear power, and six that had seriously considered nuclear power have decided not to proceed further. Antinuclear advocates are no longer confined to the political fringes. Included in their ranks are the prime minister of Austria, the president of the Philippines, and the leaders of the main opposition parties in Great Britain and West Germany. Prime Minister Ingvar Carlsson of Sweden, once pronuclear, assessed the damage to his country after Chernobyl and concluded, "Nuclear power must be got rid of."[3]

Most nuclear programs were far from healthy even before Chernobyl. Plant construction worldwide has fallen by half from its peak in 1980, and is likely to drop much further by 1990. Even France, which almost alone has held firmly to its vision of a nuclear-powered future, will be adding at most one reactor annually in the early nineties. Prior to Chernobyl it appeared that the Soviet Union would be building as many nuclear plants as the rest of the world combined during the nineties. But in the aftermath of Chernobyl, the Soviet program is almost certain to be set back. Nuclear power's share of world electricity could actually be lower in the year 2000 than it is in 1987.[4]

Nuclear power's fading fortunes stem from the fact that it is an energy source whose implications many citizens find troubling. Some argue that we need a new generation of nuclear technology and a new commitment to safety. However, a growing number of people, including qualified scientists, believe that nuclear power as it has so far been developed is unacceptable. They claim that nuclear power's long-term costs—in waste disposal, threats of terrorism, and accidents—exceed any conceivable economic benefits.

Chernobyl will force policymakers to consider nuclear power's future far more carefully than they have so far. It showed graphically—and tragically—that we all share the global environment, forcing a reassessment of the nuclear endeavor. As we approach the end of the twentieth century, Albert Einstein's observation that "the unleashed power of the atom has changed everything save our modes of thinking" seems ever more profound.[5]

An Accident Report

8 At 1:00 A.M. on April 26, the operators at the fourth and newest nuclear reactor at Chernobyl were one full day into a special test. They wanted to see whether the residual energy of a spinning turbine could provide sufficient power in case of an emergency shutdown with loss of offsite power. In the course of the test, operators disconnected safety systems and violated operating procedures in order to press the test forward. Each adjustment caused further departures from the plant's intended performance, making it more unstable. Soon, operators were running the plant by the seat of their pants rather than the operating manuals.[6]

By 1:23 A.M. the reactor's power output had fallen to just 6 percent of its normal level, the fission reaction in the core had been slowed by the buildup of xenon gas, the emergency core cooling system had been shut down, other safety mechanisms had been disconnected, and all of the control rods that moderate fission in the reactors's core had been at least partially pulled out in order to keep the reactor going. Soviet officials say that this last violation could not have been legally authorized even by General Secretary Gorbachev.[7]

The operators pushed ahead, apparently oblivious to the fact that the reactor had become dangerously unstable. Slowly, the reactor's power output began to rise—to the intended level and then far beyond. Operators pushed the emergency button known as AZ-5 that sends the control rods back into the core to stop the fission reaction. But the control rods failed to fall fully into the already deformed core. A few seconds later, shocks were felt in the control room, followed almost immediately by two large explosions.[8]

Soviet officials report that in 4.5 seconds the power level of the reactor rose more than 2,000-fold to 120 times its rated capacity, a surge that can best be described as a "slow nuclear explosion" that ripped open the 2,000 fuel rod and control channels in the reactor's core. (Nuclear bombs release their energy in billionths of a second and are far more powerful.) The rupture of the fuel rods caused the cooling water to flash into steam, resulting in a huge explosion that was directed

upward by the surrounding graphite mass. The 1,000-ton concrete slab above the reactor was blasted aside, and nearby observers saw a spectacular fireworks display as hot nuclear fuel and graphite were hurled into the night sky (described by the Soviets as a "rapid fuel relocation").[9]

At Three Mile Island, where the reactor's core partially melted in 1979 and contaminated the plant, the reactor vessel kept all but a tiny portion of the dangerous materials from spreading across the Pennsylvania countryside. The Ukrainians were not so fortunate. For the first time ever, the lethal radioactive contents of a large power reactor were exposed to the atmosphere. Helicopter pilots who arrived at the scene a short time later reported that they could look directly down through a gaping hole in the reactor building and see the glowing core within. Meanwhile, the exploding reactor had started 30 separate fires that threatened to engulf the Chernobyl 3 reactor located just a few meters away.[10]

Local officials were at first unaware of the dimensions of the unfolding tragedy. The reactor adjacent to the destroyed unit was not shut down until 16 hours after the accident and two nearby units were kept operating for 24 hours. Authorities arriving from Moscow who had been told that the reactor was "under control" found an intensely burning mass of graphite instead.[11]

By the end of the day, the Soviet Union's top nuclear officials were directing what was soon to be one of the largest peacetime emergency operations ever. Civilian workers and military forces were mobilized from around the country to assist in the effort. However, uncertainties persisted, as shown by the frantic efforts of Soviet embassy officials in several countries to gather information about graphite fires. To fight the fires and slow the release of radioactive materials, helicopters dropped 40 tons of boron carbide, 800 tons of limestone, 2,400 tons of lead, and thousands of tons of sand and clay on the reactor.[12]

These efforts were only partly successful. Although the main fire was extinguished within several hours, saving the adjacent reactor, the graphite-encased core continued to smoulder for several days. Radia-

tion levels, after falling initially, gradually built up over the following days. (See Figure 1.) This is because the large amount of materials dropped on the core caused it to grow hotter and release more radioactive isotopes. Finally, on the eleventh day after the accident, liquid nitrogen was pumped under the reactor, cooling it and causing radiation levels to plunge.[13]

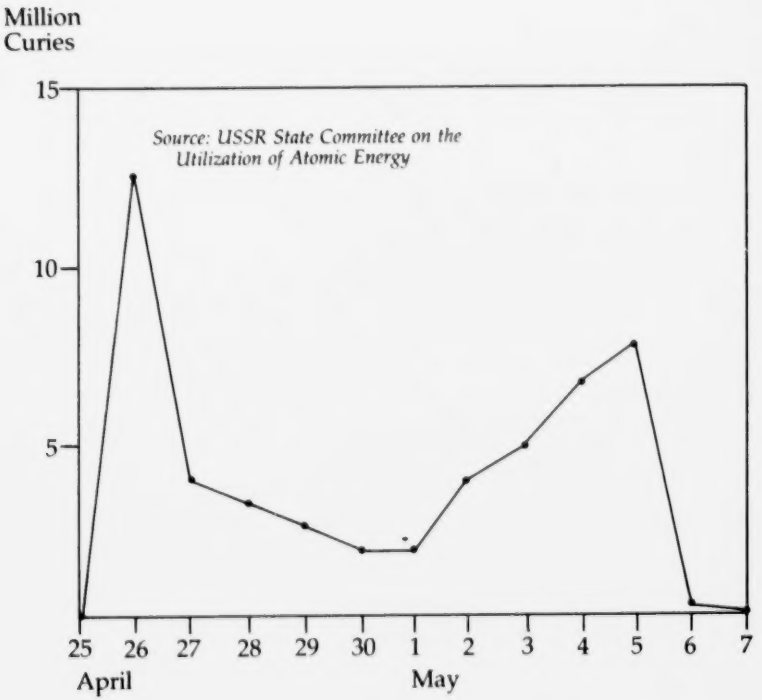

Figure 1: Daily Release of Radioactivity from Chernobyl

"It was not until 36 hours after the accident that Soviet officials evacuated Pripyat's 49,000 residents and all others within 10 kilometers of the plant."

The immediate casualties of the Chernobyl accident were workers at the plant and rescue workers who went to the scene in the first few hours. The Soviets reported that the plant operators in the control room survived, but at least three men in the adjacent turbine hall were killed by fire and radiation. Firefighters, in what can be described as acts of heroism or blind obedience to orders, climbed onto the roof of the reactor building, receiving intense radiation doses as their boots stuck to the melting asphalt.[14]

Most of the 29 people who died from radiation exposure in the first few months were among the 50 workers who received direct radiation in excess of 500 rads (units of absorbed radiation). Altogether, 237 people who received doses between 100 and 500 rads were hospitalized with acute radiation disease. Although most are still alive, their long-term prospects are not good. They are at considerably increased risk of developing cancer for the rest of their lives.[15]

The health effects of high levels of radiation exposure are well known from investigations at Hiroshima and Nagasaki as well as from accidents involving workers at nuclear facilities. Doses over 500 rads cause severe damage to the body's tissues, particularly those that grow the fastest. Doctors report that many of the Chernobyl victims died slowly and painfully from radiation burns. Bone marrow that produces the body's red blood cells was also damaged in many patients. Efforts by an international team of doctors to transplant fresh bone marrow or fetal liver cells into about 20 patients were of limited success: Within three months three-quarters of the patients were dead, many killed by infections that overwhelmed their damaged immune systems.[16]

It was not until 36 hours after the accident that Soviet officials evacuated Pripyat's 49,000 residents and all others within 10 kilometers of the plant. Later, the evacuation zone was widened to 30 kilometers and then further expanded to include selected areas that received high levels of fallout. Altogether, 135,000 people were moved. In Kiev, 80 kilometers south, 250,000 schoolchildren were sent away for an early summer vacation a few weeks after the disaster. Although Western experts question the delays, the Soviets say that they moved

people as soon as wind conditions indicated, and that prior to the evacuation, exposure was limited by keeping people indoors. Once begun, the evacuation appears to have been carried out with remarkable efficiency.[17]

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Soviet authorities have described only in general terms the extent of the fallout in the vicinity of the plant and in more distant parts of the Soviet Union. What is known is that most of the people evacuated were still away from their homes eight months later. A new town is being built to house displaced people, and authorities do not appear to be planning to resettle Pripyat or Chernobyl in the near future. Clouds approaching the area were seeded to prevent local rainfall, and 150,000 meters of special film was laid to reduce radioactive dust. Large areas of forest were cleared and topsoil stripped off to lower the radiation hazard. A "sarcophagus" was constructed around the reactor itself, which eight months after the accident was still at a temperature of 127° C. A series of dikes was built to protect the Pripyat River which feeds the Dnieper and the water supply system of Kiev. Thousands of conscripted workers were brought in to assist in these tasks.[18]

The weather helped minimize the impact of the accident in the area around the reactor. Fire carried the fallout high into the air, and the metropolitan area of Kiev, home to 2.4 million people, was largely spared because winds blew away from the city during the worst period. Moreover, meteorologists report that there was no rainfall as the initial plume spread west, ensuring that most of the fallout would occur outside the Soviet Union, largely over the Atlantic and Arctic Oceans, as well as Scandinavia and Western Europe.[19]

Despite help from the weather, the Ukraine suffered a health and ecological disaster. Most of the evacuated people are unlikely to ever return to their homes, according to Soviet officials. They also face a heightened risk of cancer for the rest of their lives. The soil in the region is of a type that will retain radioactive particles for a long time, and the food chain may be contaminated for many years. Broad international participation in assessing the ecological and agricultural damage would be useful since the world has a good deal to learn from

"Potentially health-threatening levels of radioactive materials were deposited more than 2,000 kilometers from the plant and in at least 20 countries."

the first large-scale radiological contamination from a nuclear power plant. Soviet authorities have indicated interest in international collaboration, but it is unclear how much they will allow.[20]

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Scientists estimate that between 3 and 4 percent of the radioactive isotopes in the Chernobyl core were released to the environment—about 7,000 kilograms of material containing 50 to 100 million curies of radioactive materials, over 1,000 times the amount released at Three Mile Island. They included up to 50 radioactive isotopes with half-lives (the time it takes to decay to half the original concentration) ranging from two hours to 24,000 years. Some were inert gases that rapidly dissipated in the atmosphere, posing no significant health threat outside the immediate area, but others were long-lived, biologically active elements that fell across Europe and around the world.[21]

Scientists were surprised by the extent of the contamination. The initial explosion and the graphite fire that followed lifted radioactivity high into the atmosphere where it was picked up by high-speed winds. During the first day and a half, winds blew toward the northwest, carrying the invisible radioactive cloud into the Soviet republics of Byelorussia, Latvia, and Lithuania, as well as northern Poland and across the Baltic Sea into Scandinavia. From the second through the fourth days, the winds blew west and southwest, blanketing the Ukraine, southern Poland, Austria, Czechoslovakia, southern Germany, Switzerland, northern Italy, and eastern France. Radiation was also carried south across Romania, Bulgaria, Yugoslavia, and Greece. By the fifth day, the winds turned northwest again, taking the fallout into central Germany, the Netherlands, and Great Britain. Finally, the winds turned northeast, carrying the cloud toward Moscow and the central Soviet Union.[22]

The Chernobyl cloud left an extraordinarily complex pattern of fallout that may never be fully understood. Potentially health-threatening levels of radioactive materials were deposited more than 2,000 kilometers from the plant and in at least 20 countries. Some parts of Europe directly under the plume received little fallout, while others got larger amounts. The plume was composed of many different

elements with varying weights and half-lives. Their deposition was heavily influenced by rainfall that washed radioactive particles out of the air. Local topography caused the radioactive runoff to concentrate along valleys and in reservoirs, forming "hot spots." West German researchers found that over a distance of 100 kilometers, radiation levels varied by a factor of 15. Similarly, levels 100 kilometers northwest of Stockholm reached 10 times those in the capital.[23]

A person can be injured by direct exposure to radioactive materials, by inhaling radioactive gases and dust, or by ingesting contaminated food or water. Chernobyl led to all three exposures, but the largest concern outside the immediate vicinity has been ingestion. Radioactive materials falling on soil or vegetation were consumed directly by people or by grazing animals, concentrated in their tissues, and transferred to people in meat and dairy products.

Scientists agree that the largest number of deaths will be due to cancers caused by exposing living tissues to ionizing radiation that damages cells' genetic material. The most serious threat is to unborn fetuses and children. In the first days, the widely dispersed radioisotope iodine 131 was of most concern since it concentrates in the thyroid gland, where it can cause nodules that can become cancerous within a few years. The eight-day half-life of iodine 131 helped limit human exposure, as did food restrictions and the administration of iodine solutions that limit absorption of radioactive iodine. (The Poles dubbed this concoction "Russian Coca-Cola.") However, medical examinations of children in eastern Poland at the time indicate that many received enough iodine 131 to present a serious health threat.[24]

Other radioisotopes released at Chernobyl will last much longer. These include cesium 137 which has a half-life of 30 years; strontium 90, 28 years; and plutonium 239, 24,000 years. Cesium is of greatest long-term concern: It is biologically active and was released in enormous quantities. Scientists estimate that one-tenth to one-sixth as much cesium 137 was emitted at Chernobyl as has entered the environment from all nuclear weapons tests to date. Since most above-ground weapons testing was performed in remote areas, the human impact of the Chernobyl fallout is—by the standards of previous human experience—substantial.[25]

In the weeks following the accident, fresh vegetables in many parts of Europe had levels of radioactivity above limits recommended by health authorities. (See Table 1.) In addition, cattle grazing on contaminated grass were soon producing milk with significant levels of radioactive materials. Governments were generally unprepared to deal with these new health threats and issued a wide variety of

Table 1: Maximum Reported Radiation Levels in Europe after Chernobyl[1]

Country	Ground Exposure Rate	Iodine 131 in Milk		Cesium 137 in Milk
		Reported	National Safety Guideline	
	(micro-Roentgen/hour)		(Becquerels/litre)	
Soviet Union[2]	15,000	—	2,000	—
Poland	1,000	2,000	1,000	—
Sweden	500	2,900	2,000	44
Romania	350	2,900	185	10
Austria	240	1,500	370	—
Czechoslovakia	200	1,000	1,000	110
West Germany	200	1,184	500	300
Switzerland	150	1,850	3,700	629
Yugoslavia	150	1,000	—	380
Turkey	100	360	—	—
United Kingdom	100	1,136	2,000	443
Italy	—	6,000	500	230

[1]Measured April 29 to May 13, 1986, except for Czech, Italian, and Yugoslavian Cs-137 data, measured early June.
[2]Soviet figure for edge of evacuated zone. Levels would have been higher closer to the plant.

Source: World Health Organization, "Summary Review of Measurement Results Relevant for Dose Assessment, Update Revision No. 7," Copenhagen, 1986.

often-conflicting food restrictions. For several months, perhaps 100 million people altered their diets.[26]

16 In southern West Germany, the local government of Konstanz severely restricted milk and vegetable consumption, while the adjacent Swiss canton of Thurgau took almost no precautions. Sweden adopted a comprehensive national program, including extensive monitoring. Consumption of spring vegetables, berries, and freshwater fish in some areas was discouraged, and most of Sweden's cattle were kept in their barns until meadows had been approved for grazing, a process that was not completed until the end of the summer. As far away as Brazil and Thailand, the sale of dairy products imported from Europe was banned. Scientists believe that the restrictions reduced Chernobyl's cancer toll, although they are unsure how much.[27]

Europeans were confused by and critical of what they perceived as paternalism, incompetence, and outright deception by government health and environmental officials. Most countries were unprepared to deal with the fallout, and many handled the situation badly. In Italy, local governments and citizens' groups were left to monitor radiation levels; even four months after the accident, significant amounts of cesium were discovered in wild mushrooms, veal, rabbit, and mutton. In the United Kingdom, scientists and politicians have criticized a deliberate National Radiological Protection Board effort to downplay the health effects.[28]

As the radioactive cloud passed over eastern France, the French government repeatedly stated that it had missed the country and life could continue normally. Weather maps were issued showing sweeping turns in wind currents as they steered around the country. But in a few days independent observers found evidence that France had received fallout comparable to that in adjoining nations. The government explained its mishandling of the information by the fact that officials were on holiday.[29]

International organizations did little to resolve the confusion. The International Atomic Energy Agency (IAEA) provided no food or

"As far away as Brazil and Thailand, the sale of dairy products imported from Europe was banned."

health recommendations. The World Health Organization made its first official pronouncement a week after the accident, and then issued only broad warnings. The European Economic Community (EEC) did adopt interim limits on radiation levels in crops and restrictions on importing fresh food from Eastern Europe for three weeks. However, the standards were lower than in most member countries, and compromised by political considerations. Since the accident, EEC ministers have considered creating a radiological information service and permanent food standards.[30]

Scientists believe that in most areas radiation levels will fall sufficiently to permit resumption of normal life within a year or two—primarily due to the diluting effects of rain, wind, and ploughing. Some problems may persist, however. One example is Switzerland's Lake Lugano, where authorities banned fishing in early August when its fish were found to have concentrations of cesium up to six times the EEC standard. Radioactive materials may remain in lake sediments and some types of agricultural soils for several years.[31]

In Scandinavia, the Sami people (also known as Lapps), whose diet consists of reindeer meat, were severely affected due to heavy rainfall during the passing of the Chernobyl cloud. Some 97 percent of the reindeer slaughtered in late summer had radioactivity above the level recommended for human consumption. Norway and Sweden banned the consumption of reindeer meat and placed large quantities in frozen storage. Norway has raised the allowable limit so that some of it may be consumed. Sweden is considering a similar relaxation, though many citizens question the soundness of such a change. Because of the long half-life of cesium 137, the reindeer that graze in radioactive areas are likely to be contaminated for at least seven years, and human consumption of radioactive reindeer meat during that period could have a large cumulative impact. Already Chernobyl has proved to be a catastrophe for the delicate Lapland ecosystem and the endangered culture of the Sami people.[32]

The long-term health dangers of the fallout cannot be accurately predicted. Scientists have broadly reliable estimates of the cesium contamination, but the diverse pathways by which people can receive

radiation, the variations in exposure over short distances, and lack of local monitoring equipment compound the unknowns. The threat from iodine 131 is particularly vague because most of it disappeared before it could be measured. Even greater uncertainty surrounds the impact of low levels of radiation on human beings. Medical scientists agree that low doses carry some cancer risk, but disagree on how much.

Scientists estimate that about 50 million curies of long-lived radioactive isotopes entered the environment, and the current medical consensus is that this should raise the cancer rate in the Soviet Union by less than 1 percent, mainly as a result of exposure to cesium 137. However, experts at the IAEA Chernobyl meeting in August 1986 argued heatedly over the best assumptions for making fatality estimates. Scientific uncertainties led to projections of Soviet fatalities as low as 5,100 and as high as 100,000. One-half to three times as many additional deaths are likely outside the Soviet Union. A U.S. government study projects 14,000 cancer deaths. Dan Beninson, chairman of the International Commission on Radiological Protection, estimates that 5,100 cancer deaths will result, while some scientists expect even fewer.[33]

These figures represent a serious health threat, but one that is smaller than many others that societies live with. Swedish scientists, for example, estimate that people living in heavily contaminated areas are about half as likely to die from cancer caused by Chernobyl's fallout as in an automobile accident. And pollution from coal-burning power plants kills thousands of people who contract respiratory disease or cancer each year.[34]

Other scientists believe that the medical establishment has seriously underestimated the health threat posed by exposure to radiation. John Gofman, a professor of medical physics at the University of California, estimates that there will be between 600,000 and 1 million cancers due to Chernobyl, about half of which will be fatal. He believes that recent epidemiological studies in Hiroshima and Nagasaki show that the survivors are still developing new cancers, which means that the risk of exposure to low-level radioactivity is higher

than the medical experts assume. This disagreement highlights the great uncertainties that surround the effects of low levels of radioactivity four decades into the nuclear age. Only many years of careful evaluation of the affected people can establish whether Gofman is right when he calls Chernobyl the most serious industrial tragedy in history.[35]

Whether or not it is the most serious disaster ever, Chernobyl is almost certainly the most expensive. In the Soviet Union, direct expenditures come to $3 billion according to official estimates and up to $5 billion according to independent economists. (See Table 2.) The cleanup at Three Mile Island, where the radioactive core remained entirely within the reactor vessel, is still under way seven years later, and those costs alone will pass $1 billion. The temporary shutdown of all four Chernobyl reactors in 1986 caused regional power shortages. The costs of Chernobyl could eventually climb to over $10 billion if all of the indirect expenses are included.[36]

Table 2: Estimated Direct Financial Losses in the Soviet Union from the Chernobyl Accident, June 1986

Loss	Estimated Cost
	(million dollars)
Replacement cost of plant	1,040–1,250
Lost agricultural output	1,000–1,900
Site cleanup	350–690
Health care for victims	280–560
Lost export earnings	220–660
Relocation of residents	70
Total	2,960–5,130

Source: "Economic Consequences of the Accident at Chernobyl Nuclear Power Plant," *PlanEcon Reports*, Issue 19-20, quoted in "The Cost of Chernobyl," *European Energy Report* (Financial Times Business Information), June 13, 1986.

Other countries are adding up their costs, and some plan to submit bills to the Soviet Union. In the United Kingdom, sheep farmers have claimed losses of $15 million. In Sweden, costs are projected at more than $145 million, mainly for radiological monitoring and compensation of farmers. The West German government reports it will pay farmers at least $240 million for lost sales. Poland estimates that it lost $35 to $50 million in hard currency sales to Western countries.[37]

Several Western governments plan to present claims against the Soviet government at the World Court in The Hague, but the Soviets flatly deny that Western countries have suffered significant damage. Indeed, one top Soviet official has suggested that funds should flow in the opposite direction, to compensate for damage that exaggerated Western press reports did to the Soviet Union. Since no established legal principles underpin most of these claims, lawyers do not expect the World Court to require compensation.[38]

The dimensions of the Chernobyl tragedy have led planners in many nations to reassess the potential effects of a disaster at one of their own nuclear plants. The extent of the damage depends on how much of a reactor's radioactive core is released, how those materials are dispersed by weather or accompanying explosions, whether spent fuel stored at the site is also dispersed, and how efficient evacuation procedures are. Some accidents will undoubtedly be similar to Three Mile Island in which only very small amounts of radioactive materials were released, but nuclear engineers have identified scenarios involving the world's other major reactor types that could result in contamination similar to Chernobyl's.

Population density near Chernobyl was relatively low, the weather spared local communities, and evacuation was efficient—conditions that might not prevail in future accidents. A 1982 U.S. government study found that a worst-case accident at many U.S. nuclear plants would result in more serious health, environmental, and economic damage. At nuclear plants located in densely populated areas, as many as 100,000 immediate deaths and $150 billion of economic damages could result.[39] (See Table 3.)

Table 3: Estimated Worst-Case Accident Consequences for Selected Nuclear Power Plants in the United States[1]

Plant	Location	Deaths		Financial Losses
		Early	Cancer	
		(thousands)		(billion 1980 dollars)
Salem 2	Salem, N.J.	100	40	150
Peach Bottom 2	Peach Bottom, Penn.	72	37	119
Limerick 1	Montgomery, Penn.	74	34	213
Waterford 3	St. Charles, La.	96	9	131
Susquehanna 1	Berwick, Penn.	67	28	143
Shoreham	Wading River, N.Y.	40	35	157
3 Mile Island 1	Middletown, Penn.	42	26	102
Indian Point 3	Buchanan, N.Y.	50	14	314
Millstone 3	Waterford, Conn.	23	38	174
Dresden 3	Morris, Ill.	42	13	90

[1]Plants listed are those in densely populated areas.

Sources: Sandia National Laboratory, "Estimates of the Financial Consequences of Nuclear Power Reactor Accidents," prepared for the Nuclear Regulatory Commission, Washington, D.C., November 1982; Critical Mass Energy Project.

If the Chernobyl accident had occurred at one of the two Biblis plants on the Rhine River near Mannheim, West Germany, the 30-kilometer evacuation zone would have included 2.3 million people. And if the winds were to blow north, the fallout could affect an additional 2.7 million people in the Wiesbaden and Frankfurt metropolitan areas, both within 50 kilometers. A similar accident at Three Mile Island would require the evacuation of about 250,000 people, and at the Indian Point plant near New York City, about 1.5 million.[40]

Ironically, the U.S. nuclear industry has argued, even after Chernobyl, to reduce the 10-mile (16-kilometer) emergency planning zones around particular U.S. plants. Its case is based on optimistic

accident scenarios and is intended to ease the burden of evacuation planning at controversial plants. But most of the evidence indicates that even the current 10-mile zone is too limited and could leave hundreds of thousands of people in considerable danger should a serious accident occur. Chernobyl demonstrated the unpredictability of radioactive fallout and the need to make conservative plans that take account of a range of scenarios. In the initial stages of any accident there is likely to be great confusion. Moreover, evacuation will inevitably be more difficult in Western countries due to the less regimented nature of societies and the availability of private cars that could quickly clog major roads. These factors suggest the need for wider emergency planning zones and stricter policies than those now in place.[41]

The Political Fallout

The first indication that a nuclear disaster had occurred came not from Soviet officials—who for almost three days denied there had been an accident—but from Swedish technicians 2,000 kilometers away at Forsmark. Even in Sweden, the rising radiation levels were detected not by the Swedish government's sophisticated array of atmospheric monitoring equipment but by routine inspection of workers' feet at a nuclear power plant. Beginning with the accidental discovery of Chernobyl's radioactive cloud, through weeks of warnings, misstatements, deceptions, and corrections, the international community showed itself ill-prepared for a nuclear emergency.[42]

For the Soviet Union, the Chernobyl accident was an untimely test of its avowed new policy of *glasnost*, or openness. Like an actor overcome by stage-fright during a debut performance, the Soviet leadership reverted to its old style of defensive secrecy in the early days of the Chernobyl tragedy. Although Kremlin officials decided within 12 hours that the accident was serious enough to merit a top-level commission, two days passed before a terse, three-sentence public announcement was read on Radio Moscow.[43]

"Through weeks of warnings, misstatements, deceptions, and corrections, the international community showed itself ill-prepared for a nuclear emergency."

Authorities, beset by intense international criticism, released a trickle of new information in the following days—not enough to placate concern, but torrential by the standards of a country that does not normally announce airplane crashes. Officials continued to assure the world that the reactor was "under control" long after its contents were spread across the Ukrainian countryside. Newspaper coverage was limited to short articles on the inside pages, accompanied by long, sensationalist accounts of past nuclear accidents in the West. May Day celebrations in Kiev got far more press attention than did the ongoing disaster at a power plant only 80 kilometers away.[44]

As is often the case in the Soviet Union, people relied on gossip for their information, much of it gleaned from Western news broadcasts that were sometimes inaccurate. Panic began to develop in some areas: There were reports that large numbers of children jammed the Moscow train station, arriving from Kiev to "visit relatives." On the eleventh day following the disaster, when the release of radioactivity at Chernobyl was brought under control, *Pravda*, the official Communist party newspaper, published its first extensive description of the accident. One week later, Gorbachev made his first televised statement to the nation.[45]

After the Gorbachev address, information flowed more freely. Newspapers presented the Chernobyl firefighting and cleanup operation in terms usually used to describe the defense of "Mother Russia" during World War II. These reports were juxtaposed with angry accusations of sensationalism on the part of the Western media. However, Soviet officials refused to address some important issues. Detailed information on fallout levels found outside the immediate area of the plant was not made available, nor was there any public discussion of long-term cancer risks. Nonetheless, Chernobyl apparently marked a turning point in Soviet information policy. Authorities handled subsequent transportation and mining accidents with unprecedented forthrightness, perhaps in recognition of their unsuccessful attempts to downplay the Chernobyl disaster.[46]

Soviet credibility had already suffered considerable damage. In the first few days following the accident, the dearth of official information

led to strong denunciations from Western governments. In Sweden, the energy minister, Birgitta Dahl, called the Soviets' information dissemination on the accident "unacceptable." It does not appear that even close Soviet allies received any advance warning of the three-day-late Tass announcement. Later, in an apparent effort to mollify the Eastern Europeans, Soviet officials quietly announced a plan to pay precious hard currency for some of the agricultural produce its allies could not sell in the West.[47]

Western press coverage of the Chernobyl disaster included distortions of its own. Exaggerated accounts of the accident were fueled by a lack of solid information, a general tendency to sensationalize, and Cold War fervor on the part of some news organizations. Among the worst examples were a United Press International story claiming that 2,000 people had been killed, and the tabloid *New York Post's* headline: "Mass Grave—15,000 Reported Buried in Nuke Disposal Site." Some U.S. government officials who are normally strong supporters of nuclear power encouraged the distorted reporting by publicly doubting the official Soviet casualty figures. These stories angered Soviet officials who remain bitter about what they consider cynical efforts to exploit the tragedy.[48]

Although East-West tensions continued to complicate efforts to deal with Chernobyl's aftermath, Europeans were soon more concerned with immediate health threats, for example, whether it was dangerous to go for a walk or drink the water. Across Europe, vegetable stands carried signs indicating radiation levels or advertising the fact that the produce came from uncontaminated areas. "Chernobyl is everywhere" became a rallying cry for those opposed to nuclear power and was scrawled on buildings and subway cars. The sudden realization that eating lettuce or allowing children to play in a sandbox could pose a health threat created anxieties that transcended ideology. It also led to widespread mistrust of authorities who seemed to provide confused or distorted information on the fallout.

Public opposition to nuclear power did not begin with Chernobyl. The accident was simply the worst of a series of developments that had already disenchanted many people. Organized opposition began

in Europe and the United States in the mid-seventies. Antinuclear organizations prospered in many countries, fueled by local opposition to the development of many nuclear facilities. Although nuclear opposition is pressed by a minority, its goals are supported by a large and growing number of people.

By the time of Chernobyl, nuclear power had faded from public debate: Some of the most controversial facilities had been stopped and nuclear expansion had slowed dramatically in many countries. Most major political parties, both left and right, remained committed to nuclear power, but the issue was rarely discussed in national election campaigns. Everything changed on April 26. Within weeks, large antinuclear demonstrations were organized across Western Europe, including massive rallies in Rome and at controversial nuclear facilities in West Germany, where hundreds of demonstrators and police were injured. By late August, over 1 million Italians had signed petitions calling for a referendum on the nuclear program. In Switzerland, petitions were gathered for the third nationwide antinuclear referendum in six years. In Eastern Europe, where public demonstrations and petition drives are rarely permitted, Chernobyl led to unprecedented displays of concern, and most governments reacted with unusual tolerance.[49]

Over two-thirds of the people in most countries are now against building more nuclear plants, numbers that have increased significantly since Chernobyl. (See Table 4.) Indeed, about half the people in Europe favor the shutdown of existing facilities. These attitudes are only partly caused by Chernobyl. Andrew Holmes of the *Energy Economist* writes, "Nowhere does nuclear power command the enthusiastic assent of a large majority of the population."[50]

Since Chernobyl, local and regional organizations with links to women's groups, farmers' cooperatives, labor unions, and other groups have begun to voice their opposition to nuclear power. Several West European communist parties have turned against nuclear power, as have some business groups and sportsmen. Farmers from northern Sweden dumped 10 tonnes of cesium-laden hay in front of government buildings in Stockholm. In the Netherlands, workers at

Table 4: Public Opposition in Selected Countries to Building Additional Nuclear Power Plants[1]

Country	Before Chernobyl	After Chernobyl
	(percent)	
United Kingdom	65	83
West Germany	46	83
Italy	—	79
United States	67	78
Yugoslavia	40	74
Canada	60	70
Finland	33	64
France	—	52

[1]Wording and polling techniques varied, but data are broadly comparable. Pre-Chernobyl figures are from polls taken between 1982 and 1986.

Source: Worldwatch Institute, based on Gallup and other polls.

one of the country's large power companies voted even before Chernobyl not to work on new nuclear projects. In Great Britain, the Trade Unions Council, a coalition of the country's labor unions, narrowly defeated a call for the abolition of nuclear power.[51]

In many cases women have led the move against nuclear power. For example, in Finland, some 4,000 women have pledged not to have children until the government changes its nuclear policy. Marjo Liukkonen, a leader of the movement, says, "We decided to declare a childbearing strike because we consider the effect of nuclear power on future generations. Men look at nuclear power on the basis of short-term profit." In Sweden, 45 percent of the men want to get rid of nuclear power, but 75 percent of the women do.[52]

The reaction to Chernobyl varied greatly by country. (See Table 5.) West Germany has Europe's second largest nuclear program, and provides one example of the way political forces are influencing nu-

Table 5: Reactions to Chernobyl in Selected European Countries

Country	Citizen Response	Political Response
Austria	Antinuclear movement victorious; protests carried to neighboring countries.	Government decides to dismantle sole plant; develops formal non-nuclear stance.
Finland	Opposition doubles to 64 percent; 4,000 women go on childbearing strike.	New orders postponed.
France	Public angered by disinformation on fallout but opposition limited.	Major parties remain pronuclear; safety study ordered.
Italy	100,000 protest in Rome; 1 million petition for nuclear referendum.	Major parties turn against the nuclear program; national conference held.
Poland	Protest in eastern Poland; petition to halt construction, pending inspection by IAEA.	Nuclear program slowed; safety study ordered.
Sweden	Heavy fallout redoubles nonnuclear consensus; many call for rapid phaseout.	Government establishes commission to consider detailed plans for previously agreed phaseout.
Switzerland	Petition drive launched for local and national referenda on nuclear power.	Government postpones expansion but remains committed to nuclear power.
United Kingdom	Environmental groups launch campaign to halt nuclear expansion; citizens block waste sites.	Labor and Liberal parties call for phaseout; Conservative government affirms nuclear course.
West Germany	Large demonstrations; Green Party gains in state elections.	Government establishes cabinet-level post for nuclear safety; Social Democrats call for phaseout.
Yugoslavia	Opposition nearly doubles; local antinuclear groups are formed.	Planned plants postponed pending safety evaluation.

Sources: Various news articles and personal contacts.

clear power and vice versa. Since the sixties, West German governments have consistently held that nuclear power is essential to Germany's future. This solidarity was disturbed only slightly by protests in the early eighties. However, soon after Chernobyl, public opinion turned decisively against nuclear power, forcing the major political parties to rethink their positions. Public pressure was brought to bear on state governments and political parties. In Hesse, the state government is run by a coalition of Social Democrats and Greens who decided to push for a phaseout of nuclear power. In Bavaria, on the other hand, the conservative government is still strongly pronuclear. Nationally, the ruling Christian Democratic government hopes to placate public concern with a new Ministry of Environment and a nuclear safety program. The opposition Social Democratic Party now favors a complete phaseout, however.[53]

In the United Kingdom, Chernobyl reinforced public reaction to the country's own nuclear problems. A series of mishaps at the Sellafield nuclear reprocessing plant has leaked radiation into the soil and Irish Sea in recent years, causing widespread anxiety. Soon after Chernobyl, the British government decided to move forward with test drilling for several low-level radioactive waste dumps. Local villagers responded by staging well-publicized sit-downs in front of bulldozers—which halted the drilling indefinitely. Many people transferred their anger from these local concerns to the broader nuclear issues. Enthusiasm for the troubled British nuclear power program has reached an all-time low, as has trust in nuclear authorities.[54]

In France, Chernobyl's political fallout was less severe. Although the share of the French population opposed to further nuclear power development reached 52 percent in late 1986, this is the lowest such figure in Europe. French pride in their nuclear program is linked to a desire to be a leading technological power, free of foreign domination. Politicians rarely criticize the nuclear program, and journalists are less aggressive in pursuing nuclear stories than in most Western countries. At base, the French trust their elite. As one French nuclear official puts it, "It would be totally unhealthy, counterproductive, and damaging for technical issues to be dealt with in public and constantly exposed to criticism and statements by just anyone."[55]

Two weeks after Chernobyl, the French government came under attack when it was revealed that information had been withheld on the health threat from Chernobyl. Soon after, officials admitted that a French nuclear plant had suffered a critical malfunction two years earlier but reports of that accident had also been kept from public attention. These revelations led to criticism of what French editorial writers called "nuclear disinformation." However, after a committee was established to look into the charges, criticism quickly faded.[56]

The Chernobyl accident also stirred opposition in Eastern Europe, which currently has little nuclear power but big plans for its development. The radioactive cloud made a deep impression on many Eastern Europeans; lack of previous public debate on nuclear issues meant that most people had little understanding of nuclear hazards. A Polish woman told reporters, "At first I was frightened, but now that I have heard all the explanations, I am still frightened." Farmers in some countries had to leave fresh produce to rot in the fields and got only token compensation from the government.[57]

A Polish citizens' petition demanding reconsideration of the country's nuclear program was submitted to the People's Parliament. In an unprecedented move, the government agreed to a reassessment. This has led to new safety measures and to a slowdown in the country's nuclear program. The East German government was also petitioned to reconsider nuclear power but it remains unclear whether there will be any substantive response. In Yugoslavia, strong local opposition groups have sprung up. And in the Soviet Union, the Moscow Trust Group attempted a street demonstration to protest the government's inadequate health warnings. They urged that the country's graphite reactors be shut down until they could be operated safely. Although the KGB thwarted this protest, it represented an extraordinary stirring of public concern.[58]

Though less dramatic, Chernobyl's political fallout outside Europe was still significant. From Taiwan to South America, antinuclear sentiment grew, and political parties responded by at least moderating their support of nuclear power. South Korea, which has the Third World's strongest nuclear program, now has an antinuclear movement for the first time. In the Philippines, Chernobyl pushed the

newly elected president Corazon Aquino to finalize her decision to dismantle the country's only nuclear plant.[59]

30 In the United States reaction to Chernobyl was somewhat tempered by distance, but several controversial nuclear plants still under construction faced renewed opposition after Chernobyl. Local groups and state governments are arguing with some success that nuclear plants in New Hampshire, New York, and North Carolina should not be allowed to operate because of the difficulty of quick evacuation and the refusal of local authorities to participate in evacuation planning. In Hanford, Washington, a government-owned reactor similar to the Chernobyl design and used to produce plutonium for nuclear weapons has been shut down for extensive modifications. State political leaders are seeking the plant's permanent closure. A new national organization has been formed to encourage the early shutdown of some plants. In Oregon, however, a public referendum on shutting down the state's Trojan nuclear plant was soundly defeated by voters who were concerned about the potential impact on electricity prices.[60]

One of the most important developments since Chernobyl is nuclear power's emergence as an issue that can damage relations between neighboring countries. The accident showed that the effects of a nuclear accident can cross borders with impunity, and in Europe, 119 nuclear power plants are located within 100 kilometers (62 miles) of a national frontier. The large rivers that commonly form national boundaries provide cooling water necessary for plant operation. Moreover, plants in these areas often provoke less local opposition.[61]

Denmark, where the parliament voted in 1985 never to develop nuclear power, is close to reactors in East and West Germany as well as Sweden. Of particular concern is the Swedish plant at Barsebäck, just 30 kilometers from Copenhagen, across the Øresund Strait. Danish officials fear that the evacuation of their capital—whose 1.5 million residents are almost a third of Denmark's population—could cause the virtual collapse of the national economy. Concern over Barsebäck has risen steadily since the late seventies; after Chernobyl the Danish parliament voted to ask Sweden to close Barsebäck, a request the

"An important development is nuclear power's emergence as an issue that can damage relations between neighboring countries."

Swedish government has agreed to consider. In light of a general feeling among Swedes that the Danish request is well founded, there is a good chance that Sweden's government will decide to shut the plant in the next five to ten years.[62]

Cross-border disputes are not being settled so diplomatically elsewhere. At Cattenom, France, just 10 kilometers from both Luxembourg and West Germany, four 1,300-megawatt reactors (one of the world's largest power complexes) are being built on the Moselle River. Some 334,000 people live within 30 kilometers of the plant and 1.5 million live within 50 kilometers. Public opposition mounted quickly after Chernobyl, and demonstrators from Germany and Luxembourg crossed the border to protest at Cattenom. Local West German governments requested that the project be reconsidered. It is on swampland that has already caused some buildings to sink and does not meet stricter German safety standards. French authorities have refused to yield, claiming that the plant will be as safe as any. They view the opposition as a manifestation of German "neurotic anxiety" and flatly assert that other countries have no right to question a plant located on French soil.[63]

The Wackersdorf nuclear reprocessing plant has badly strained relations between non-nuclear Austria and pronuclear Bavaria. Located near the Bavaria-Austria border in Germany, Wackersdorf is intended to process nuclear spent fuel into high-level waste that would be shipped 500 kilometers to salt caverns in northern West Germany. Since Chernobyl, weekly demonstrations involve thousands of West Germans and Austrians. At one point, Bavarian officials threatened to stop the Austrian vice-chancellor from crossing the border to attend a Wackersdorf protest. The Austrian government has formally asked the German government to stop the plant on safety grounds. The West German foreign minister's reply was that his government is moving forward "without pause for thought."[64]

Tensions have also flared between Ireland and the United Kingdom. Ireland is particularly concerned about the Sellafield reprocessing plant, which has illegally dumped large amounts of radioactive waste into the Irish Sea and has a history of mismanagement. A report by

the British House of Commons Environment Committee states that the Irish Sea is "the most radioactive sea in the world." Many Irish politicians have asked that the plant be closed, but British officials have refused to consider it.[65]

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Outside of Europe, the most contentious cross-border dispute is between Hong Kong and China. For years, Hong Kong utilities, the colony's British governor, and Chinese officials have been developing plans for a two-unit 1,800-megawatt nuclear station at Daya Bay, just 50 kilometers from Hong Kong. The $3.4-billion plant, China's largest joint venture ever and its first major nuclear power project, is to be financed by Hong Kong banks. Hong Kong utilities plan to buy 70 percent of the power.[66]

Following Chernobyl, 1 million people—20 percent of the adults in Hong Kong—signed petitions objecting to the Daya Bay plant, mainly due to fears that in an accident the people in Hong Kong would be trapped. China, however, has dismissed the complaints and Hong Kong's legislative council, bowing to Chinese pressure, has let the project proceed. It is ironic that the historic reunification of Hong Kong and China, scheduled for 1997, is complicated by a nuclear project conceived by British colonial rulers but now aggressively defended by Beijing's communist government.[67]

The question of how nuclear projects are managed and even whether they should be built is fast being recognized as an international issue in which nations have a moral duty to consider the effects on neighboring states. The 1986 IAEA meeting in Vienna resulted in an agreement—supported by the Soviet Union—to provide immediate notification of radioactive leaks that threaten other countries. Similar proposals have been made to the Nuclear Energy Agency, which includes most Western nuclear nations, and to the European Economic Community.[68]

IAEA delegates also agreed to provide coordinated assistance in the event of future accidents. Some representatives wanted to go further. Hans Blix, the Swedish secretary-general of the agency, says that there is "growing support" for a study on international financial

compensation for future accidents. And the Soviet Union has called for an expert committee to develop international safety standards.[69] These efforts to implement international standards and controls are laudable but should have happened two decades ago.

How Safe is Nuclear Power?

As of early 1986, Chernobyl 4 had the best operating record of any nuclear power reactor in the Soviet Union. Indeed, its 83-percent load factor in 1985 made it one of the top nuclear plants worldwide.[70] How could a reactor whose basic indicators showed excellent performance have been involved in the worst accident in the history of nuclear power? That is a question of fundamental importance not only for Soviet nuclear authorities but for concerned citizens everywhere. Chernobyl, like Three Mile Island, has cast a spotlight on unresolved safety problems.

Four months after the accident, representatives of 62 nations met in Vienna under the auspices of the IAEA to hear the official Soviet account of the accident and cleanup efforts. Soviet officials presented a candid and chilling report that described in detail the accident and its results. Although nuclear scientists have long recognized the potential for serious accidents and worked to prevent them, the magnitude of Chernobyl exceeded what many thought to be the worst "credible" accident scenario. It brought reality to what had been a realm of cold theoretical studies. The world's nuclear leaders listened in stunned silence to the Soviets' account of the tragedy.

Western nuclear experts went to Vienna skeptical of the Soviets' explanation of the accident, but came away convinced that the account of gross operator errors was true. Soviet officials brought considerable supporting evidence and the story itself could hardly have been intended to restore the tarnished image of their nuclear program. The Soviets also admitted to design flaws that had made the accident possible. For a society in which public criticism of official mistakes is rarely tolerated, the bloodletting at Vienna was extraordinary.[71]

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The Soviet nuclear power program is over 30 years old and is the product of some of the country's best scientific and engineering talent. Chernobyl 4 was a uniquely Soviet design called an RBMK, a graphite-moderated, water-cooled reactor. It was first employed in the fifties because it was relatively easy to build and did not require any technologies that the Soviet Union did not then possess. Today, 20 of the Soviet Union's 44 reactors are RBMKs and seven more are under construction. (The Soviet Union is also building pressurized water reactors similar to the most popular Western design.)[72]

Since Chernobyl, nuclear scientists have been wrestling with its implications for the safety of reactors around the world. Western nuclear industries and their critics have a big stake in this debate, and a few weeks after the accident, the U.S. nuclear industry bought full-page newspaper advertisements to proclaim, essentially, "It cannot happen here." Lord Marshall, who heads the United Kingdom's Central Electricity Generating Board, called a press conference to describe the supposed weaknesses of Soviet nuclear technology. And U.S. Energy Secretary John Herrington, who has done little to promote nuclear safety in his own country, became a vocal critic of the Soviet nuclear program, criticizing its safety standards and the decision to quickly restart two surviving reactors. Some nuclear opponents, on the other hand, overstated the similarity of the Chernobyl reactor to Western designs.[73]

In the rush to judge Soviet technology, many commentators proceeded with limited knowlege of Soviet equipment and procedures. Although many critics focused on the graphite moderator as an intrinsically dangerous part of the RBMK design, for example, the use of graphite was not the main cause of the accident. Chernobyl 4 did have features that would not be permitted in other countries, but it was not a "piece of junk" as some commentators implied. The reactor was only two years old and included several recent design improvements. Other countries, particularly the United Kingdom, rely on far older nuclear technology.[74]

A major feature distinguishing the RBMK from most reactors in use today is its "positive void coefficient." In an accident, if the water

"Engineers do not know whether any containment would have survived the Chernobyl explosion."

coolant changes to steam, the fission reaction speeds up, making it possible for the reactor to run out of control, a characteristic that is not permitted under nuclear regulations employed in most Western countries. Soviet officials have pledged to make changes to the RBMKs that will remove the positive void coefficient and to upgrade their control systems, which do not meet post-Three Mile Island Western standards.[75]

Most Western reactors have a secondary containment structure made of concrete to ensure that in an accident the dangerous radioactive materials will not be dispersed. Chernobyl lacked a full secondary containment, but it did have a containment building with thick walls and a "suppression pool" beneath it. This containment system is less complete, but it is similar to the ones used at boiling water reactors in the United States. Moreover, engineers do not know whether any containment would have survived the Chernobyl explosion. Morris Rosen, the top safety official at the IAEA, says that the RBMK technology is generally up to international standards: "Chernobyl was designed adequately for a loss-of-coolant accident. . . . It was not designed for the accident that occurred, but I would repeat that the containment was adequate for what it was designed to do."[76]

Chernobyl marks the second nuclear accident to end in the destruction of a large reactor core. Although Three Mile Island and Chernobyl were distinct in many ways, there are threads that link them: Operators made mistakes that were complicated by inadequate control systems, and design defects made the accidents possible. John Ahearne, a former commissioner of the U.S. Nuclear Regulatory Commission (NRC) writes, "Both reactors are very sensitive. The positive void coefficient makes the Chernobyl type reactor extremely sensitive to perturbations in the system. With its small once-through cooling system, the B&W (Three Mile Island-type) reactor is well known within the U.S. nuclear reactor industry as being our most sensitive reactor."[77]

In the United States, the deficiencies revealed at Three Mile Island led the NRC to require extensive modifications of reactors in operation and under construction. Some of these changes are still under way.

Many in the industry argue that the new regulations are burdensome and unnecessary, but critics say the new standards are still too lax and are being poorly enforced. They claim that the fundamental reforms recommended by the President's Commission on the Accident at Three Mile Island were never implemented.[78]

Soviet officials have announced a similar retrofit program. The changes will make safety systems more difficult to override and prevent operators from withdrawing too many control rods. The plants will be fueled with more highly enriched uranium to stabilize the core. Additional neutron absorbers will be added to eliminate the positive void coefficient. In the summer of 1986, limited modifications were made, and most of the RBMKs were up and running by the fall, including the two undamaged Chernobyl units. It is unclear how long the more substantial changes will take, but officials say the western Soviet Union does not have enough generating capacity to allow extended shutdowns.[79]

It cannot be assumed that the Soviet nuclear program will be back on track soon. Valery Legasov, who led the Soviet delegation to Vienna, said, "Before, the paramount factor was the economics of the reactor. . . . Now we are forced to lose part of this efficiency. . . . Such a big accident will have an impact on our national energy program. . . . It will also perhaps slow down the construction of new nuclear stations." Legasov said that the Soviet Union intends to pursue the development of a new reactor type, and subsequent reports indicate that the RBMK program will be discontinued.[80]

The experience of the United States after Three Mile Island shows that even minor adjustments to nuclear plants are expensive and time-consuming. Close inspection of plants after years of neglect revealed many problems, and solving them helped make new U.S. nuclear plants decidedly uneconomic. The Soviet regulatory process and industry structure are far different. But Chernobyl has shaken the confidence of Soviet planners, and the fact that the USSR State Committee for the Supervision of Nuclear Safety is being restructured suggests the extent of their soul-searching.[81]

Both the Three Mile Island and Chernobyl accidents can be traced to human mistakes, and more specifically, to the "man-machine interface" at the center of complex technology. The President's Commission on the Accident at Three Mile Island concluded that serious operator errors were the major cause of the accident. The commission stated in its 1979 report:

> Equipment can and should be improved to add further safety to nuclear power plants, and some of our recommendations deal with this subject. But as the evidence accumulated, it became clear that the fundamental problems are people-related problems and not equipment problems. . . .To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organization, procedures, and practices—and above all—in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry.[82]

The conclusions of the official Soviet report on Chernobyl are similar:

> The prime cause of the accident was an extremely improbable combination of violations of instructions in operating rules committed by the staff of the unit. . . . The accident assumed catastrophic proportions . . . because all the negative aspects of the reactor design . . . were brought out by the operators.[83]

The fact that operators helped cause both accidents means that plant control systems and operator-training programs need to be upgraded. It does not mean, however, that the solution is to replace human operators with robots. Computer systems can malfunction or be misprogrammed, and some aspects of plant operation require human judgment. The interaction between operators and their plants can and should be improved. Engineers in the Soviet Union and the West are now considering this issue.[84]

Complacency and arrogance helped sow the seeds of disaster in the Ukraine. Statements by Soviet officials and the actions of the Chernobyl operators indicate an utter confidence in their technology.

When Pennsylvania's Governor Thornburgh toured nuclear facilities in the Soviet Union in 1979, he was informed that nuclear safety was "a solved problem" and that it would soon be possible to safely operate a reactor in Red Square. Three Mile Island, he was told, had little relevance to the Soviet nuclear program. Ironically, overconfidence and the excellent performance of the Chernobyl plant may have encouraged the operators' blatant violations of safety procedures.[85]

The bitter Soviet experience may encourage those who run the world's nuclear programs to reverse their "it cannot happen here" campaigns and rededicate themselves to improved safety. Although the light water plants that are now the world's norm are significantly different from the Soviet RBMKs, they share a most important trait—vulnerability to catastrophic accidents. Nuclear engineers still hope to develop an inherently safe reactor, one that would not melt down or explode even if all safety systems failed, but so far none has even left the drawing board.[86]

Light water reactors have a number of weaknesses, including a power density far higher than that of the Soviet RBMK model. This presents inherent dangers with which engineers must cope. Even after shutdown, the core of a large reactor emits as much heat as a large steel-melting furnace and must be actively cooled. Engineers have identified scenarios in which a light water reactor could go quickly and dangerously out of control, leading to the destruction of multiple safety systems and the containment. For example, explosive destruction of a reactor core could turn the pressure vessel into a mass of flying projectiles that would destroy the secondary containment. Chernobyl demonstrated that once operators lose control of a reactor, the results can be sudden, unexpected, and destructive.[87]

If the primary coolant system in a pressurized water plant were to fracture, the water would boil into steam with potentially disastrous results, including a so-called meltdown in which the overheated radioactive core would destroy the containment. To prevent such an accident, engineers have spent decades designing special safety systems. These include backup power units, redundant electrical wiring

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and piping for essential systems, an emergency core cooling system, and if all else fails, a steel vessel surrounding the reactor and a secondary concrete containment structure. The result is a system whose complexity may exceed that of any other machine. But that complexity can yield unpleasant surprises. Some unforeseen chain of events could render the advanced safety systems as futile as the French Maginot Line in 1940. Before Chernobyl, safety engineers had not considered catastrophic steam explosions to be a major risk, and before Three Mile Island, which almost suffered a hydrogen explosion, the potential for hydrogen buildup in a damaged reactor had not seriously worried the industry.[88]

Prior to Three Mile Island and Chernobyl, nuclear power supporters frequently advertised the fact that "no one has been killed by radiation in a nuclear power plant accident." The absence of catastrophic accidents was taken as proof of nuclear power's safety, leading to an unrealistic view of the state of nuclear technology. In a 1984 study on high-risk technology, Charles Perrow, professor of sociology at Yale University wrote:

> If the safety systems have worked so far, why call this a high-risk system? One answer is that the "defense in depth" safety systems have worked, limiting the course of accidents. But a more accurate and less reassuring answer is that we simply have not given the nuclear power system a reasonable amount of time to disclose its potential. . . . We are only just beginning to uncover the potential dangers that make any prediction of risk very uncertain.[89]

Two years after Perrow's book was published, Chernobyl confirmed his thesis and brought these dangers to broad public attention. In order to assess nuclear hazards critically, engineers have developed a modeling tool known as probabilistic risk assessment. Analysts study accident scenarios and failure probabilities of critical components, estimate safety margins, and develop overall estimations of risk. Government-sponsored assessments in the United States and West Germany have estimated that core-damaging accidents should occur once every 10,000 years of reactor operation, and a post-Three Mile

Island study by the Oak Ridge National Laboratory in 1982 raised the risk to once in 4,000 reactor years. Even if the more optimistic figure is right, with 500 nuclear plants in operation, there would be one core-damaging accident every 20 years.[90]

Probabilistic risk assessments must rely on uncertain assumptions that do not always reflect actual plant conditions. Two critical circuit breakers at the Salem plant in New Jersey failed twice in a single week, although each failure had been estimated to have a 1 in 33,000 chance of occurring. In addition, redundant safety systems can be destroyed simultaneously, leaving no safety margin. The Browns Ferry fire in 1975 destroyed several redundant electrical systems, shutting down the control room and threatening catastrophe.[91]

A 1986 analysis by the Paris-based Nuclear Energy Agency concluded that probabilistic risk assessments are useful in evaluating particular technical issues but of uncertain validity when assessing overall safety. So far, nuclear power is more accident-prone than expected. Three Mile Island occurred after 1,500 years of worldwide reactor operation, and Chernobyl occurred after another 1,900 years. (See Figure 2.)

With the overall size of the nuclear industry continuing to grow rapidly, the chances and likely frequency of a serious accident are increasing as well. If the current accident rate were to continue, there would be three additional accidents by the year 2000. At that point, with 500 reactors in operation, core-damaging accidents would occur every four years. Scientists in Sweden and West Germany have used this data to estimate a 70-percent probability that another such accident will occur in the next 5.4 years. Scientists are even more uncertain as to how many of these accidents would have modest health and environmental effects, like Three Mile Island, and how many would be catastrophic, like Chernobyl.[92]

Another measure of risk is the availability of private insurance. The U.S. insurance industry has made nuclear accidents uninsurable at any price. Indeed, most homeowner, automobile, and even contact lens insurance policies exclude liability in the event of a nuclear

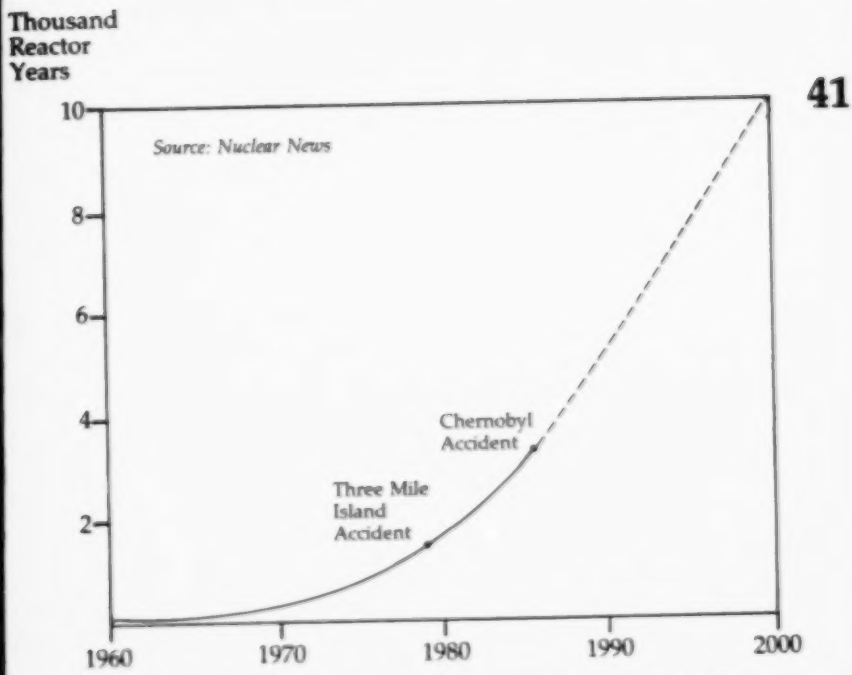

Figure 2: Cumulative Years of Nuclear Reactor Operation Worldwide, 1960-85, with Projections to 2000

power plant accident. The federal government has intervened with the Price Anderson Act to limit the liability of nuclear plant operators to $655 million, less than 1 percent of the estimated cost of a worst-case nuclear accident. The nuclear power industry has its own cooperative agreement to provide this limited coverage. Beyond that, victims would have no recourse other than to ask the U.S. Congress to appropriate special funds.[93]

While critics charge that the Price Anderson Act is an unfair subsidy of the nuclear industry, the industry replies that without such an exception to normal liability laws, it would not be able to survive. The problem is twofold: An accident of Chernobyl's scale or greater could bankrupt insurance companies, and insurers are not convinced by the available evidence that such an accident is a sufficiently unlikely event. Whatever the true risks of nuclear power, they appear to be beyond the limits that the insurance industry considers reasonable.[94]

Despite post-Three Mile Island improvements, nuclear plants are still plagued by problems. In the United States, there were almost 3,000 plant mishaps and 764 emergency shutdowns in 1985, up 28 percent from 1984. The average U.S. nuclear plant was shut down six times in 1985, and the industry as a whole averaged two shutdowns per day. More than a sign of trouble, emergency shutdowns are sudden, violent procedures that stress many parts of a nuclear plant and could impair safety.[95]

Although most shutdowns were due to minor problems, at least 18 were serious accidents that could have led to core damage. One of nuclear power's fundamental problems is that even the most trivial incident could one day lead to catastrophe, a fact made possible by the enormous complexity of nuclear power systems. Significant nuclear incidents have already been initiated by hungry field mice, a worker's loose shirttail, and an improperly used candle.[96]

Nuclear plant managers in other countries struggle with similar problems. The Nuclear Energy Agency, which represents countries in North America, Western Europe, and Japan, has recorded an annual rate of over 1,000 emergency shutdowns. A 1986 meeting found general agreement that emergency shutdowns pose dangers and that their frequency should be reduced. Data show that there are substantial variations in plant load factors and shutdown rates in different countries. Despite major investments in improved safety systems, operating procedures, and training, performance has improved substantially in only a few countries. In others it has declined. (See Table 6.) France, which is now widely regarded as the world leader in nuclear power technology, actually has the highest rate of forced shutdowns.[97]

Table 6: Average Load Factors and Emergency Shutdown Rates in Selected Countries' Nuclear Power Plants

Country	Average Lifetime Load Factor	Average Frequency of Emergency Shutdowns[1]	
		1981-83	1984-85
	(percent)	(number/reactor/year)	
Canada	77.1	4.4	4.0
West Germany	71.1	1.6	1.1
Japan	62.9	0.6	0.2
Sweden	62.7	3.8	3.2
France	61.9	8.8	6.9
United States	56.1	—	6.0
United Kingdom	51.3	1.9	2.6

[1]Emergency shutdown frequency data unavailable for U.S. 1981-83, France 1981, Canada 1981, Great Britain 1981, 1982, and 1985.

Source: *Nuclear Engineering International*, June and September 1986.

Japan has steadily improved its plant performance since the seventies, a result of extensive analysis of problems, intensified preventive maintenance, and operator training. When Japanese plants are closed for refueling, engineers often extend the shutdown to uncover problems before they lead to emergencies. Whether other countries can replicate Japan's performance is unclear. In the United States, mismanagement of nuclear plants has become common, as have safety violations and attempts to hide mishaps from regulators. These problems were highlighted in 1986 when all nine plants being operated or built by the Tennessee Valley Authority, the country's largest nuclear program, were shut down due to deepseated management problems. Utility executives and regulators express confidence that such problems can be resolved, but so far their track record is not encouraging. NRC Chairman Lando Zech threatened in early 1987 to close down the nuclear plants of those utilities whose financial problems jeopardize safety.[28]

Government authorities play an important role in nuclear safety. In most countries an independent agency is given responsibility for regulating the nuclear industry, even if plants are government-owned as in China, France, and the Soviet Union. In practice, however, there is often a close relationship between the nuclear industry and its regulators. In France, for example, state-owned companies build and operate nuclear plants, a state company fuels them, and a government ministry runs the overall program and regulates the industry. Most of the country's top nuclear officials have worked both sides of the fence. In the United States, where legislators tried to separate industry promotion from regulation in 1975 via a law that divided the two functions between agencies, the effectiveness of the regulatory process is still in question. Dissident NRC Commissioner James Asselstine says, "This commission believes its job is to protect the industry and not the public. . . . There's a misplaced sense of optimism even to the point of ignoring the messages we're getting from the operating experiences of the plants."[99]

Even if nuclear regulation is made more efficient, its effectiveness is difficult to verify. In the United States and many other countries, safety features are added piecemeal and are poorly integrated into plant design. Over time, the complexity of the regulatory process and the plants themselves could adversely affect safety. The spate of new regulations that followed the accident at Three Mile Island had to be adapted to dozens of distinct plant designs, an enormously complex task. A study by the Electric Power Research Institute found that a typical plant now has over 30,000 valves, 40 percent of which may be redundant. The French nuclear industry has had fewer such problems, in part because most of its plants are standardized and are of more recent design.[100]

Although the U.S. industry and its critics have complained about safety standards for years, no one seems to have an effective strategy for improving them. Meanwhile, as over 30 plants neared completion in the early eighties, the federal government greatly reduced its spending on nuclear safety research, leaving many serious safety concerns unresolved. According to the National Research Council, the federal safety program is "weakened by indecisive management, lack of direction, and political neglect."[101]

"The world now has a growing number of aging nuclear plants, many beginning to show signs of deterioration."

There are other problems on the safety horizon. The world now has a growing number of aging nuclear plants, many beginning to show signs of deterioration. By 1990 there will be 35 plants that are at least 25 years old, by 1995 there will be 66, and in 2000 there will be 150. The nuclear industry has little experience with aging nuclear plants, but many have already developed unanticipated problems. Among the most serious are corrosion of steam generators and embrittlement of steel pressure vessels due to neutron bombardment. Both of these problems are widespread in some types of plants, involve critical components, and are difficult to remedy. The problems of aging plants were highlighted in late 1986 when Virginia's 13-year old Surry nuclear plant suffered a "guillotine break" in a hot water pipe. Four workers were killed by steam burns and the plant was closed for at least several months while the plumbing system is thoroughly checked. Inspectors have found extensive corrosion of pipes in unexpected areas, indicating once again that nuclear plants are aging in unexplained and dangerous ways.[102]

Problems are also posed by the growing number of plants in the Third World. Politically unstable nations with limited engineering know-how are adopting a technology that demands the highest technical standards. Nuclear construction projects in Brazil, India, Mexico, and other countries are undermined by mismanagement, shoddy construction, substandard steel and concrete, and bribes to inspectors. Construction delays and cost overruns are often as bad as the worst in the United States. Several severely problem-plagued plants are due to begin operation in the next few years, and many people are worried. Large antinuclear demonstrations took place in Brazil and Mexico in 1986. Protesters have urged their leaders to consider the path chosen by the Philippines: Decommission the plants before they ever get a chance to operate.[103]

One result of Chernobyl is a move to implement some form of international safety regulation. Chernobyl showed that people have reason to be concerned not only about plants within their borders but also those outside. Both Soviet General Secretary Mikhail Gorbachev and West German Chancellor Helmut Kohl have called for an international conference on safety issues. Although the IAEA has interna-

tional responsibility for nuclear safety, its involvement has been minimal so far, accounting for only 7 percent of its budget. Although the agency has offered safety reviews to member countries since 1983, only eight had hosted inspections by the time of Chernobyl.[104]

Since Chernobyl, the Soviet Union, the United Kingdom, West Germany and other countries have requested that IAEA teams inspect their plants. However, the IAEA has the resources to make only cursory inspections and has no enforcement powers. Plans for safety budget increases, from $11 million to $15 million, may enable the IAEA to conduct more safety-related research, implement voluntary safety guidelines, and step up its voluntary inspection program. However, these funds are miniscule compared to the size of the international nuclear industry, and such measures can hardly be considered a substitute for regulation. Primary responsibility will remain with national authorities. There are benefits to be gained from more cooperation, but the complexity of nuclear plants and sensitive issues of national sovereignty probably preclude an effective international safety regime.[105]

Harnessing nuclear energy has created opportunities for a new kind of disaster. Like natural catastrophes such as hurricanes or earthquakes, we do not know exactly where or when the next nuclear accident will occur, only that it almost certainly will. Whatever the fate of nuclear power, the world must do much more to reduce the frequency of accidents, and prepare to deal with the consequences when failures occur. One danger is that, like generals who prepare for the last war, the world's nuclear planners may be planning for the last meltdown. Three Mile Island and Chernobyl provide important lessons, but future accidents are unlikely to replicate either. Nuclear safety issues must be addressed broadly and important reforms introduced soon.[106]

Alvin Weinberg, the former director of Oak Ridge National Laboratories and a leading U.S. nuclear analyst says:

> It would be claiming too much to insist on the impossibility of an accident in an LWR [light water reactor] that breaches a

> western containment. All we can say is that the likelihood of such an accident appears to be extremely small, probably much smaller than in a Chernobyl-type reactor. . . . The ultimate question is, can we accept a technology whose safety is measured probabilistically? . . . In a participatory democracy such as ours, the answer to this cannot be given by any but the public.[107]

This is indeed the ultimate question. Nuclear safety is no longer an issue that can or should be left to the experts. Even the best nuclear scientists cannot reach definitive conclusions about the safety of today's nuclear plants. Nor can they answer the central philosophical question: "How safe is safe enough?" Only individual people working through the political process can resolve that issue.

Revising the Nuclear Dream

The experience of nuclear planners during the past decade can be summed up in a single phrase: lowered expectations. In the early seventies, when nuclear programs were started, many governments had lavish ambitions. At one point the IAEA added up various national plans and projected that 4.45 million megawatts of nuclear power would be in place by the year 2000, with much more to follow. This is more than 17 times the current nuclear capacity and more than double the size of the world's entire electricity system in 1987.[108]

National and international projections of nuclear capacity have declined steadily for over a decade. Today, the IAEA projects that the world will have just 372,000 megawatts of nuclear power in 1990 and 505,000 megawatts in the year 2000—compared with 256,000 megawatts in 1986. (See Table 7.) This is almost 90 percent below the agency's 1974 projection, and a 45-percent decline from the 1980 forecast. Yet even the recent projection is more hope than forecast. The current Worldwatch Institute projection based on recent reassessments is for 325,000 megawatts of nuclear capacity by 1990 and 380,000 megawatts by the end of the century.[109]

Table 7: Projections of Worldwide Nuclear Power Generating Capacity for 1980, 1990, and 2000

48

Source and Year of Projection	Projection For 1980	1990	2000
		(thousand megawatts)	
International Atomic Energy Agency			
1972	315	1,300	3,500
1974	235	1,600	4,450
1976	225	1,150	2,300
1978	170	585	1,400
1980	137	458	910
1982	—	386	833
1984	—	382	605
1986	—	372	505
Worldwatch Institute			
1987	—	325	380

Sources: International Atomic Energy Agency, *Annual Reports* (Vienna: 1972-80); IAEA, "Reference Data Series No. 1," Vienna, September 1982; IAEA, *Nuclear Power: Status and Trends* (Vienna: 1984-86); Worldwatch Institute.

Even the supposedly successful nuclear programs of France and Japan are healthy only by the diminished standards by which nuclear programs are now measured. Perhaps never before has an enterprise of such magnitude suffered such a sudden turn of fortune. Even optimists now recognize that the global nuclear endeavor is in deep trouble. Yet policymakers continue to issue grossly unrealistic forecasts and are reluctant to come to grips with their fading ambitions.

Despite the slowdowns, the global nuclear enterprise is large and growing. As of mid-1986, the world had 366 nuclear power plants in operation. (See Table 8.) These facilities generate about 15 percent of the world's electricity, ranging from 65 percent in France to 31 percent

Table 8: Worldwide Nuclear Power Commitment, July 1, 1986

Country	Plants Operating[1]		Plants Under Construction		Total Commitment	
	(number)	(megawatts)	(number)	(megawatts)	(number)	(megawatts)
United States	92	78,618	28	30,849	120	109,467
France	44	38,948	18	22,210	62	61,158
Soviet Union	44	27,338	29	28,950	73	56,288
Japan	33	23,639	11	8,768	44	32,407
West Germany	16	16,114	7	6,877	23	22,991
Canada	17	11,145	5	4,361	22	15,506
United Kingdom	38	11,748	4	2,720	42	14,468
Sweden	12	9,435	—	—	12	9,435
Spain	8	5,682	2	1,979	10	7,661
South Korea	5	3,580	4	3,686	9	7,266
Czechoslovakia	6	2,380	7	3,230	13	5,610
Belgium	7	5,450	—	—	7	5,450
Taiwan	6	4,884	—	—	6	4,884
East Germany	5	1,702	5	2,532	10	4,234
Bulgaria	4	1,760	2	1,906	6	3,666
Italy	3	1,285	3	2,004	6	3,289
Switzerland	5	2,930	—	—	5	2,930
Finland	4	2,310	—	—	4	2,310
South Africa	2	1,840	—	—	2	1,840
India	6	1,244	2	440	8	1,684
Romania	—	—	3	1,680	3	1,680
Hungary	2	820	2	820	4	1,640
Argentina	2	935	1	692	3	1,627
Mexico	—	—	2	1,308	2	1,308
Poland	—	—	2	880	2	880
Cuba	—	—	2	880	2	880
Other Countries	5	1,883	1	300	6	2,183
World Total	366	255,670	140	127,072	506	382,742

[1]Includes several plants that have been shut down indefinitely.

Source: "World List of Nuclear Power Plants," *Nuclear News*, August 1986.

in West Germany, 16 percent in the United States, 10 percent in the Soviet Union, and none in most developing nations.[110]

50 The world's operating reactors represent a cumulative investment of well over $200 billion; perhaps $60 billion is spent annually building new plants and operating existing ones. Nuclear development is dominated by the most economically powerful and technologically advanced nations: Five countries have 72 percent of the world's generating capacity. This handful of countries sets the international nuclear pace, an axis of power that revolves around Washington, Paris, Bonn, and Tokyo. Even the Soviet Union has tended to follow the lead of capitalist nations in recent years, shifting from RBMKs to pressurized water reactors.[111]

The reasons for scaling back nuclear programs are almost as diverse as the countries themselves. High costs, slowing electricity demand growth, technical problems, mismanagement, and political opposition have all had an effect. Yet these various factors actually form a complex web of interrelated problems. For example, rising costs usually represent some combination of technical problems and mismanagement. Political opposition often arises because of safety concerns or rising costs.

The United States led the world into the nuclear age and now appears to be leading it out. The last year a U.S. nuclear plant was ordered that was not subsequently canceled was 1974. Meanwhile, orders for 108 reactors have been withdrawn, representing a capacity comparable to all U.S. plants now in operation and under construction. Yet U.S. nuclear capacity continues to rise as projects started in the early seventies are finally completed. In 1985 and 1986, 14 plants were completed, and another 19 are to be completed in the next three years. After 1989, however, only three more nuclear plants are scheduled and these are all in jeopardy. Even if plants continue to be delayed, U.S. nuclear capacity is likely to peak between 1990 and 1992 and will then slowly decline as aging plants are decommissioned.[112]

The impending collapse of the U.S. nuclear construction business is driven primarily by economic forces. The rate of growth in U.S.

electricity consumption has fallen from 7 percent per year in the early seventies to 1.8 percent since 1980. While this led to a general scaling back of construction programs, most utility executives cut their nuclear projects first and most heavily, sometimes after spending billions on construction.[113]

Orders and cancellations for coal plants have about balanced since 1980, while 55 nuclear projects were canceled and none ordered. The main reason for this discrepancy is cost. Nuclear plants in the United States that cost less than $200 per kilowatt of generating capacity in the early seventies carried price tags of $750 per kilowatt in 1980, $1,900 per kilowatt in 1984, and over $3,500 per kilowatt for the 14 reactors scheduled for 1987. (See Figure 3.) These figures are not adjusted for inflation and so somewhat exaggerate the cost increases; but even after adjustment, they indicate a greater than sixfold increase since the early seventies. Industry figures show that the cost of electricity from new nuclear plants (including fuel and operating expenses) now averages at least 12¢ per kilowatt-hour, while new coal plants produce at about 6¢ per kilowatt-hour and gas-fired cogeneration plants at even less.[114]

The U.S. utility industry, which in the early years was able to sweep these costs under its huge financial rug, finally has been overwhelmed by them. The industry is largely made up of private companies that must answer to investors as well as state regulators. For many, the cost overruns were sufficient to raise prices and damage their financial condition. The U.S. business magazine *Forbes* wrote in 1985:

> The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. . . . It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible. Without even recognizing the risks, the U.S. electric power industry undertook a commitment bigger than the space program or the Vietnam War.[115]

Dollars per
Kilowatt

52

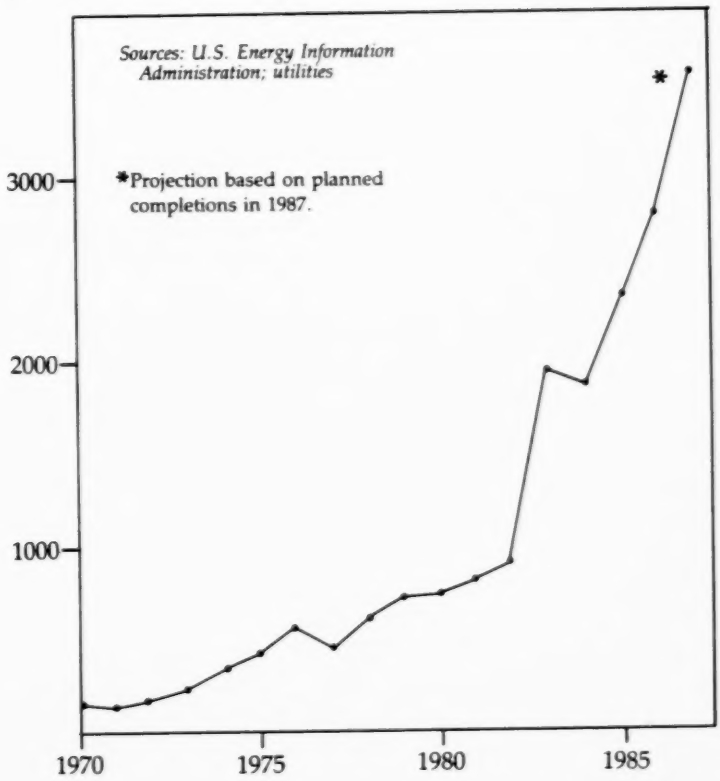

Figure 3: Average Cost of New U.S. Nuclear Power Plants Entering Operation, 1970-87

"The late eighties may be the last gasp for the U.S. nuclear construction industry."

The late eighties may be the last gasp for the U.S. nuclear construction industry. Schedules call for a major increase in nuclear power generation during the next two years. Sadly, most of the 16 plants scheduled to begin operation are economic boondoggles that should have been canceled years ago. They are subject to extensive regulatory hearings that will determine how much of their cost overruns are the fault of the utility companies and so should be shouldered by them rather than by electricity consumers. These last few plants will push some utilities to the edge of bankruptcy and leave their customers with high bills and bitter memories.[116]

Cost increases have plagued nearly all the world's nuclear programs, but the increases have not been as large in most countries as in the United States. Typically, new European and Japanese nuclear plants are built for the equivalent of between $1,500 and $2,000 per kilowatt, although some in France are less expensive and some in Great Britain and West Germany cost far more. The cost of coal is higher in Europe and Japan, making it easier to justify expensive nuclear plants. However, a late 1986 West German government study found that nuclear power's economic advantages have been substantially eroded, leaving it with almost no advantage over coal-fired plants, the direct competition.[117]

International cost variations stem from differences in management practices and regulatory processes. Many U.S. nuclear projects are badly mismanaged, and regulation is more inconsistent than in other nations. Countries such as France that have pursued standardization have been able to better control costs. But the distinguishing characteristic of the American system is its dominance by private utilities. Elsewhere, public authorities are able to quietly pass on the financial burden of nuclear power to the public at large. In the United States, nuclear power has failed a market test that it does not have to meet elsewhere. Curiously, in other nations nuclear power is failing a political test instead—a test that Chernobyl has made more difficult. Virtually all of the world's nuclear power programs have suffered serious setbacks in recent years. (See Table 9.)

Table 9: Major Adjustments to Nuclear Programs since 1980, Selected Countries

Country	Nature of Shift	Major Reasons for Shift
Argentina	4 planned plants canceled; one under construction in danger of cancellation.	Financial problems; foreign debt; new civilian government.
Brazil	Government canceled 6 of 8 planned plants in 1986; delayed 2 others.	Financial problems; foreign debt; new civilian government.
China	8 of 10 planned plants canceled in 5-year plan of 1986.	Foreign exchange requirements.
France	Slowdown from 6 orders in 1980 to 1 each in 1986 and 1987; government still plans 90 percent of electricity from nuclear.	Slowed electricity demand growth; nuclear overcapacity.
Italy	Planned capacity of 13,500 megawatts in 2000 cut drastically; just 1 plant nearing completion.	Rising costs; safety; strong local opposition.
Japan	Capacity goals cut in 1984; construction down to 2 plants per year; government remains committed to program.	Slowed electricity demand growth; technical problems.
Mexico	Plans to build 20 plants reduced to 2.	Financial problems; foreign debt.

Spain	5 plants under construction mothballed or canceled, 1983.	Rising costs and technical difficulties; policies of new Socialist government.
Sweden	1980 referendum called for phaseout by 2010; 1986 statements affirm course.	Safety and waste concerns, intensified by Chernobyl.
United Kingdom	No plants ordered in 7 years; 5-year delay at proposed Sizewell plant.	Political pressure from environmental and local citizens' groups.
United States	54 plants canceled, no orders; de facto moratorium.	Rising costs; slowed electricity demand growth.
West Germany	Major delays in most plant construction; de facto moratorium on new orders.	Slowed electricity demand growth; political pressure by local groups and parties.

Sources: Diplomatic reports; various news articles.

In West Germany, nuclear trends are influenced more overtly by political developments than in any other country. Since the mid-seventies, German nuclear projects have frequently witnessed large and sometimes violent demonstrations. West Germany's political system is relatively decentralized, and state and local governments are extensively involved in the nuclear licensing process. Several projects have been stopped through a combination of public protests and legal interventions. West Germany has started only two nuclear plants in the past decade, and the seven that remain to be completed include some seriously troubled projects. The West German government is at work on a reprocessing plant, a fast breeder reactor, and a high-level waste disposal site, each of which has been subject to extensive legal actions and demonstrations.

Even before Chernobyl, there was little likelihood that West German utilities would order additional nuclear plants in coming years. Now, however, the debate is over when to shut down the country's existing plants. The ruling Christian Democratic Party wishes to wait until the end of their useful lives, the Social Democratic Party has called for a phaseout in ten years, and the Green Party, which made major gains in the 1987 parliamentary elections, wishes to finish the job in two. Studies have shown that even a two-year phaseout is feasible, though electricity prices would increase slightly, as would air pollution. The future of West Germany's nuclear program depends on political developments. However, it is almost certain that there will be no nuclear expansion during the nineties, and there may well be a significant decline.[118]

France's nuclear program is almost unique in having met its goals of the early seventies. The nation already gets two-thirds of its electricity from nuclear power and in 1987 has more nuclear capacity than the next three largest European nuclear programs combined. Like much of the French system, the nuclear program is highly centralized and run by state-owned companies. Reactors are built in just six years, and neither local governments nor citizens' groups have much opportunity to impede projects. Socialist President François Mitterand came to power in 1981 promising a reevaluation of the nuclear program, but soon decided to leave it untouched. Since then, the nuclear program has been nearly immune from serious political criticism.[119]

The French nuclear program nonetheless faces a self-inflicted crisis: The overarching commitment to nuclear power has led the state utility, Electricité de France (EDF), to order more plants than the country needs or can afford. EDF now has a debt of $32 billion—exceeding that of most developing countries. The president of EDF admitted in 1986 that the country will have two to four "extra" reactors by 1990, and the French labor union CFDT has estimated overcapacity in 1990 at 19,000 megawatts—the output of all 16 nuclear plants ordered since 1979.[120]

To justify its nuclear investment, EDF has shut down relatively new oil- and coal-fired power plants. It also promotes electricity con-

"Electricité de France now has a debt of $32 billion—exceeding that of most developing countries."

sumption through bargain prices, markets power to neighboring countries, and still will have to run most nuclear plants at less than half their full capacity. These actions are more an exercise in financial damage control than sound business strategy. A representative of the state-owned nuclear company (Framatome) has said: "One power plant a year is not sufficient to maintain Framatome. We would have to cut employees and close one of our two factories. It would be very difficult to start them up again." Yet one order per year is the best that Framatome can hope for, particularly given the bleak export outlook since Chernobyl. The French nuclear program may turn out to be a costly relative of the Concorde supersonic jet—a technological marvel but a financial albatross.[121]

Europe's smaller nuclear programs are also in serious disarray. Italy has faced a combination of technical problems and political opposition that for almost a decade has prevented its nuclear program from getting off the ground. Given the new antinuclear stances of most political parties, Chernobyl is likely to signal the effective end of nuclear expansion in Italy. In Spain, the government canceled three nuclear plants and mothballed two others in 1983, representing a lost investment of $8 billion. Two more are being finished, but heavy reliance on nuclear power is no longer favored by the Spanish people or the government.[122]

Nuclear expansion in the United Kingdom has slowed drastically since the late seventies, and the country has spent five years deciding whether to abandon domestic reactors in favor of an American design. Although the official report of the Sizewell Inquiry, released in early 1987, favors further nuclear expansion, as does the Conservative government, overwhelming opposition from other political parties and the public may yet stop further nuclear expansion. Meanwhile, some of the country's early reactors will likely have to be decommissioned during the nineties. In the Netherlands, there are only two small nuclear plants in operation, and after Chernobyl, the government indefinitely postponed plans to build two more.[123]

Belgium has seven plants supplying about half the country's power, but there are no plans to build more plants. Switzerland also has five

plants in operation, but no more are being built. Two public referenda on stopping nuclear expansion were narrowly defeated in 1980 and 1984 and a third is now likely. Recent polls show that the public is now strongly against more plants. Government plans to build a sixth reactor near Basel have been in limbo for almost a decade. They appear to have been shelved since Chernobyl.[124]

In Finland, four reactors are operating, but no more are under construction. Since Chernobyl, opposition has become heated, and the government has suspended plans for an additional plant. In Sweden, Chernobyl increased public pressure on the Social Democratic government to fulfill the national policy established by referendum in 1980 of phasing out all of the country's nuclear plants by the year 2010. In late 1986, a post-Chernobyl government commission determined that the phaseout could be advanced to 1997—without sharp electricity price increases—if the development of energy alternatives is accelerated.[125]

Japan's nuclear power program has moved forward slowly but more steadily than most. Beyond the 33 plants that now supply 23 percent of the country's electricity, 11 are under construction. In 1984, Japan lowered the forecast for its nuclear capacity in the year 2000 by 31 percent. Japanese utilities are now ordering just two reactors per year, a rate more likely to fall than to increase. Public concern over nuclear safety was heightened by Chernobyl, but it has not translated into any effective move to stop nuclear power.[126]

The nuclear program that is hardest to judge is the one most directly affected by the Chernobyl accident. Prior to Chernobyl, the Soviet Union and its Eastern European allies had just released their latest nuclear expansion plans, which showed the Soviet Union building two-thirds of the nuclear capacity planned worldwide between 1990 and 1995 and boosting their own nuclear output by 300 percent during the next eight years.[127]

Despite the bullish projections, the Soviet nuclear program is beset by problems that predate Chernobyl. Numerous reports have appeared of construction mishaps and delays. Most serious are problems at the

Atommash nuclear manufacturing facility in the Ukraine, designed to build equipment for all the Eastern bloc's light water reactors. It required reconstruction after wet ground caused the partly built plant to begin to collapse. It was completed five years late, and is still not producing at the planned capacity. These and other problems have caused the Soviet Union to fall short of most of its nuclear targets by amounts that are large even by the standards of overly ambitious Soviet five-year plans.[128]

Since Chernobyl, the chairman of the Soviet State Committee on the Utilization of Atomic Energy has said, "It should be stressed once more that while the Chernobyl accident was very serious it will have no effect . . . on the further development of nuclear power generating capacity in the USSR." The restart of Chernobyl's adjacent reactors and the quick retrofits of others signal a commitment to get the nuclear program back on track. To do this, the government has been forced to spend unprecedented resources on its nuclear program. International prestige is at stake and Soviet officials appear to believe that they have no other way to avoid power shortages.[129]

The Soviet Union is not a country that changes directions quickly, and the reaffirmation of its nuclear goals was predictable. But there are reasons for thinking that Chernobyl will cause a reassessment. None of the seven nuclear plants that were scheduled to begin operation in 1986 actually did. In addition, the Soviet public is now concerned about nuclear health and safety issues, and the recent tolerance of political dissent means that these concerns may be heard. Now that the nuclear program has been brought to the attention of top Kremlin officials, the depth of the problems facing it may become more apparent, and hardnosed economic judgments could replace the unrealistic goals that have driven the program so far. The Soviet Union has never been a technological leader, and the slowdown in Western nuclear programs will likely provoke further doubts.

Prior to Chernobyl, a Soviet-sponsored nuclear construction program was being geared up in Eastern Europe, with no perceptible political opposition. Although Eastern Europe currently has only a few nuclear plants, a shortage of domestic energy sources and serious air

pollution problems have aroused interest in nuclear power. But Chernobyl generated considerable opposition to nuclear power in Eastern Europe, and in some countries the opposition has turned vocal.

In Yugoslavia, protests in several republics led the government to put plans for up to eight plants on hold while a full review of the country's energy plans is carried out. Poland's latest five-year plan includes a 50 percent cut in the nuclear budget, signaling a major delay in completing the country's first four nuclear plants. East Germany and Czechoslovakia have so far indicated no change in their sizable nuclear programs. At the 1986 meeting of COMECON, six months after Chernobyl, several speeches were made in support of nuclear power. No formal numerical commitments were issued, however, as they had been at past meetings.[130]

Nuclear power plans in the Third World have been cut even more drastically than in industrial countries. Most began in the seventies under the encouragement of foreign donors. In recent years, many of these projects have been plagued by technical problems, delays, and staggering cost overruns. Mexico's plans to build up to 20 nuclear plants have virtually collapsed. Argentina and Brazil are struggling to complete much-delayed and overbudget projects started in the seventies and have put further plans on hold. Brazil's sole operating plant near Rio de Janeiro was shut down by court order following Chernobyl and work has almost stopped at the two plants being built. In India the government has invested enormous prestige and capital in a nuclear program that is now hobbled by major technical problems and escalating costs.[131]

South Korea and Taiwan are the only developing countries likely to get more than 10 percent of their electricity from nuclear power in the year 2000, and South Korea alone appears to be planning significant additional expansion. China, once the great hope for nuclear companies looking for export markets, announced in March 1986 that it would build just two plants for now. It appears to have postponed its more ambitious plans in order to avoid creating the large debts that have accompanied nuclear programs in Brazil and the Philippines.

"For some countries, a speedy end to their nuclear programs may be a prerequisite to resolving their debt crises."

Nuclear power may never have been economically viable for most developing nations, but today it is clearly a financial disaster. For some countries, a speedy end to their nuclear programs may be a prerequisite to resolving their debt crises.[132]

The world is now in transition from rapid growth of nuclear power in the late seventies and early eighties to very slow growth in the nineties. Between 1981 and 1985, 95,800 megawatts of nuclear capacity came on-line worldwide (excluding the Soviet Union and Eastern Europe), and 86,500 megawatts are scheduled for 1986-90. But just 18,400 megawatts are scheduled for 1991-95, a 79-percent decline in nuclear construction in five years. (See Table 10.)[133]

In North America and Western Europe, net additions during the nineties will probably be lower than indicated by these figures and could well be outweighed by cancellations. The wildcard in international forecasting is the Soviet Union. Official Soviet plans call for 40,000 megawatts of new nuclear plants between 1986 and 1990, but even before Chernobyl it was unlikely that that target would be met.

Table 10: Actual and Planned Additions of Nuclear Power Generating Capacity Worldwide Excluding the Soviet Union and Eastern Europe, 1971-95[1]

Period	North America	Western Europe	Other	Total Additions
		(thousand megawatts)		
1971-75	32.9	11.0	5.5	49.4
1976-80	18.2	22.8	11.2	52.2
1981-85	28.4	49.6	17.8	95.8
1986-90	35.2	36.2	15.1	86.5
1991-95	3.0	6.3	9.1	18.4

[1]Figures based on pre-Chernobyl national plans and utility surveys.

Source: "World List of Nuclear Power Plants," *Nuclear News*, August 1986.

If the Soviet nuclear program instead proceeds at its 1985 pace of five plants a year, global nuclear capacity could peak before the end of the century as the retirement of aging plants exceeds new generating capacity. Even that pace may not be sustained and the more the Soviet program is set back, the sooner the global peak will come.[134]

Beyond Indecision

Even after Chernobyl, the weight of official policy in many nations is behind nuclear power. The head of the Soviet delegation to the 1986 IAEA meeting said, "The exploitation of the atom's energy has become a realistic requirement, and is preconditioned by interests of human civilization progress." West German Chancellor Helmut Kohl told a national television audience, "Abandoning nuclear power could spell the end of the Federal Republic as an industrialized nation." Energy Secretary Peter Walker of the United Kingdom said, "If we care about the standard of living of generations yet to come, we must meet the challenge of the nuclear age and not retreat into the irresponsible course of leaving our children and grandchildren a world in deep and probably irreversible decline."[135]

The leaders of three of the world's most economically powerful nations could hardly state their faith in nuclear power more forcefully. Indeed, it is their shared apocalyptic view of a non-nuclear world that is most striking. Is it conceivable that human advancement itself depends upon this new source of power? To a growing number of scientists, politicians, and interested citizens, that assumption seems preposterous.

Chernobyl has sparked the formation of a "non-nuclear club" composed of countries with the capability and past inclination to rely on nuclear power that have decided to forgo this source of energy. (See Table 11.) Several countries, including Australia, Denmark, and New Zealand, made deliberate decisions in the early eighties not to develop nuclear power, and Sweden made plans to phase it out. Chernobyl has encouraged other countries to consider abandoning nuclear

Table 11: The Non-Nuclear Club

Country	Form of Non-Nuclear Policy	When Announced
Ireland	No official policy, but consensus against nuclear power.	late seventies
Sweden	Public referendum to phase out plants by 2010.	1980
Australia	Labor government has no-nuclear energy policy.	1983
Luxembourg	De facto moratorium; current government has explicit no-nuclear policy.	early eighties
New Zealand	Labor government policy of Nuclear Free Zone; legislation pending.	1984
Denmark	Parliament decision never to build nuclear plants.	1985
Philippines	Government decision to dismantle only nuclear plant.	1986
Austria	Government decision to dismantle only nuclear plant at Zwentendorf.	1986
Greece	Decision to forgo first nuclear plant.	1986

Sources: Diplomatic reports; various news articles.

power. It led Austria's government to decide to dismantle the country's only reactor at Zwentendorf. Corazon Aquino, president of the Philippines, announced soon after Chernobyl that the newly completed Bataan nuclear plant would be dismantled. Greece's Socialist government abandoned plans for the country's first reactor.[136]

Opposing nuclear power is now not only a respectable political position; it is fast becoming a major issue in national politics. As a result, the non-nuclear club may soon gain some new members. In West Germany, although the ruling government favors nuclear power, the opposition Social Democratic Party is pushing to close the country's plants. The future of the nuclear program there will depend on political developments, but according to Britain's prestigious *Financial Times*, "Signs are multiplying that a long slow German march away from atomic energy may already be under way." In Italy, a national referendum is planned in 1987 to decide the fate of their nuclear program. Switzerland and the United Kingdom appear to be moving slowly toward similar decision points.[137]

Austria's foreign minister shocked the international nuclear establishment when he addressed the 1986 IAEA meeting and explained his government's new stand on nuclear power:

> For us the lessons from Chernobyl are clear. The Faustian bargain of nuclear energy has been lost. It is high time to leave the path pursued in the use of nuclear energy in the past, to develop new alternative and clean sources of energy supply and, during the transition period, devote all efforts to ensure maximum safety. This is the price to pay to enable life to continue on this planet.[138]

This statement, coming not from an antinuclear activist but from a top official of the country where the IAEA is located, sent shock waves through the assembled nuclear leaders. The Austrians have their own apocalyptic vision but it is of a nuclear rather than a non-nuclear world. It reflects a disillusionment, now widespread in Europe, with the way the nuclear enterprise has turned out.

Nuclear power is not the mature industry that proponents claim, but rather a sick one sustained by government subsidies. Moreover, it is quickly losing the political life-support systems that kept it going for the past two decades. The noble visions of the fifties did not include shoddy construction practices, billion-dollar cost overruns, disinformation campaigns by government officials, thousands of tons of

accumulating nuclear waste, or exploding reactors that contaminate foodstuffs a thousand kilometers away. If Chernobyl is compared with a heart attack, it is clear that the ailment struck a patient already afflicted with cancer.

Much of the worldwide nuclear debate focuses on these issues individually. Qualified specialists disagree on most points, though the question increasingly is not about whether there are serious problems but whether or not they can be solved. Nuclear proponents argue that shoddy contruction could be halted and cost overruns contained if nuclear programs were better managed, as in France. Critics charge that France has suffered many of the same problems but that officials have managed to conceal them. Some scientists say that the nuclear waste problem can be solved by long-term geological disposal, but others believe that it is impossible to guarantee that proposed sites will remain seismically quiet for thousands of years.

Proponents claim that a new generation of inherently safe reactors could prevent future Chernobyls. Engineers are studying several designs intended to be immune from meltdown or explosion even in the event of complete system failures. These reactors would probably be smaller and more standardized than those used today. It is too early to judge their technical, let alone their economic, potential, but if the nuclear age teaches one thing, it is that promising visions do not always lead to economical power plants. The long road from initial design to commercial plants can extend for decades and must be paved with billions of taxpayer dollars. Without firm, consistent government support, success may be elusive. In any case, the fact that scientists may one day develop a reasonably safe technology is no excuse for pursuing one that is not.[139]

With so many potentially dangerous, unresolved problems plaguing nuclear power, it would be irresponsible to plunge blindly ahead. Even if nuclear power could be made economical, for example, what will happen if current waste disposal concepts prove infeasible? If the waste problem is "solved," what will happen when it comes time to decommission hundreds of contaminated reactors 15 years from now? And even if these problems are solved, how will world public

opinion react to the next major nuclear disaster, particularly if it happens on the outskirts of Chicago or in the Loire Valley south of Paris? It is the cumulative effect of these various problems that increasingly drives the nuclear debate.

Those who favor nuclear power express dismay at the extent of concern among "uninformed" citizens. Proponents agree that nuclear power poses some risks, but they believe the risks small compared to others that societies live with. The Bhopal chemical plant disaster killed more than 2,000 people, and the Mexico City earthquake killed at least 5,000, but it is the long-term and unpredictable consequences of a nuclear accident that people seem to fear the most. They are unsettled by the fact that even experts do not know how safe nuclear plants really are. Although the overall risk of a catastrophe may be small, its potential magnitude could well exceed anything that modern civilization has experienced outside of war. Fear of such a tragedy is natural, regardless of the odds.[140]

As a matter of simple practicality, it is questionable whether countries can or should base their power systems on technologies that much of the public finds objectionable. Modern societies are confronted with many controversial issues, but the nuclear endeavor is almost unmatched in the steadily mounting opposition it has faced, as shown by the opinion trends on nuclear power in the United States during the past decade. (See Figure 4.) A similar shift appears to have occurred in Europe.[141] Although Three Mile Island and Chernobyl stirred public opinion, there is more at work here. To put it simply, many people believe that nuclear power programs have gone badly awry, they do not trust officials to fix the problems, and they would rather rely on some other energy source. Public opinion now differs profoundly from official policy in many countries, and over time these differences may begin to tear at the national political fabric. The political cost of government nuclear campaigns could well exceed any potential benefits.

The extent of opposition to nuclear power may also reflect a realization of the ultimate implications of pursuing the nuclear path. Were the plans laid in the early seventies realized, by the year 2010

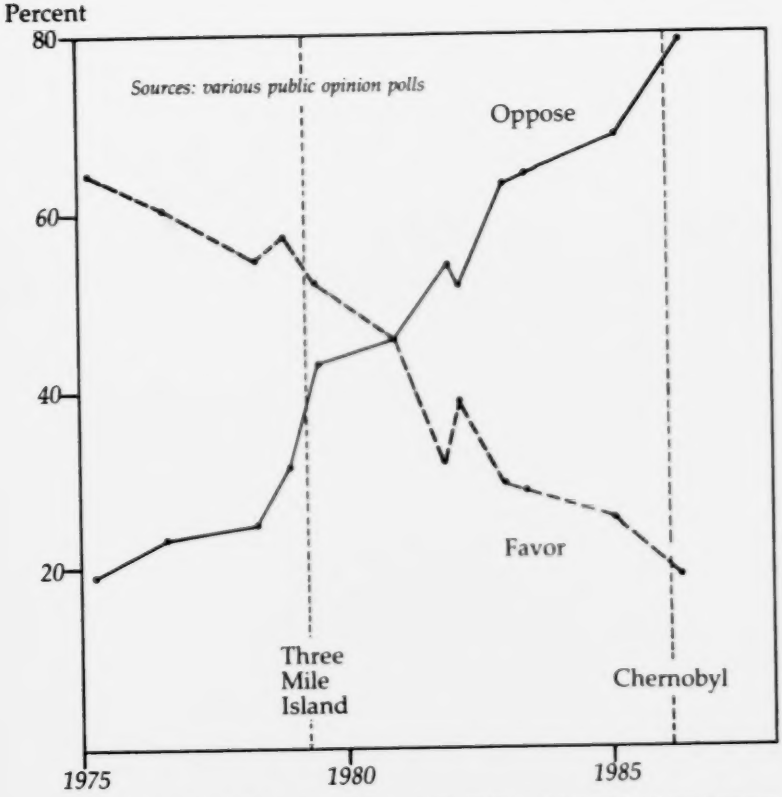

Figure 4: U.S. Public Opinion on Building More Nuclear Power Plants, 1975-86

several thousand fission reactors would be operating, many of them at the edge of large cities. Hundreds of breeder reactors would be fueled by plutonium that would be transported along the world's

highways and railroads from the reprocessing plants where it would be refined. Nuclear power plants, fuel manufacturing facilities, and waste sites would be as common in 2010 as steel plants are today. Without a major improvement in industry performance, serious nuclear accidents would become regular occurrences in the twenty-first century. Although nuclear plans have already been greatly diminished in most countries, Chernobyl revealed the underside of a vision that many technologists still pursue.

Nuclear opponents now focus on the broader issue of what kind of society we aim to create for future generations. Whereas the West German chancellor and the British energy secretary view a non-nuclear world as impoverished and joyless, the president of the Philippines and the prime minister of Austria view it as a safer and more properous world than the one nuclear planners envision.

The nuclear visionaries of the fifties foresaw a time of almost unlimited and inexpensive power, allowing such amenities as fast, clean electric cars and new gadgets that would presumably boost the standard of living. The vision did not include any changes in the nature of democratic societies. In short, nuclear power programs were formulated during a time of technological naiveté. Today, there is mounting evidence that nuclear technologies are pushing societies in a direction that has more in common with the visions of Orwell or Stalin than those of Jefferson.

Most of the world's nuclear executives point with envy to the French nuclear program. But they ignore the fact that it is made possible by a government-run energy system that can best be described as authoritarian. Public participation in decision-making is more limited than in other Western nations, and local opponents to nuclear plants have few means to stop projects that the central authorities wish to push forward. It is a system that the average citizen of the United States, West Germany, or many other countries would find unacceptable. Societies must ask: Is nuclear power so essential that we should pay for it with our democratic rights and adopt a centrally planned energy system? More fundamentally, should technology be permitted to shape society or should the choice of technologies be based on the kind of society that is desired?[142]

"The threat of terrorism has turned nuclear complexes into modern fortresses."

Nuclear programs in many countries are burdened by a legacy of official deception used to push the industry's expansion. Nuclear industry leaders have by political maneuvering managed to protect themselves from normal market forces. Energy economics can be complicated, and the industry has used this to full advantage. Industry and government-sponsored studies are full of implausible assumptions, faulty methodology, and wrongheaded conclusions. Industry representatives in France and the United States have been caught deliberately covering up faulty workmanship and minor accidents. Utility officials at Three Mile Island essentially denied that there had been an accident in the midst of the crisis. British officials repeatedly failed to report major releases of radioactivity from the government-run Sellafield fuel reprocessing plant. Whistle-blowing workers are sometimes harassed or intimidated.[143]

Nuclear power is distinct from other energy technologies in part because of the security apparatus it requires. The threat of terrorism has turned nuclear complexes into modern fortresses, with heavily armed security forces and surveillance equipment. Outside the military, modern societies have no other facilities that require this scale of protection. Langdon Winner, a California writer on technology and society, expressed his thoughts after a visit to the Diablo Canyon nuclear complex on the California coast:

> From the point of view of civil liberties and political freedom, Diablo Canyon is a prime example of an inherently political technology. Its workings require authoritarian management and extremely tight security. It is one of those structures, increasingly common in modern society, whose hazards and vulnerability require them to be well policed. What that means, of course, is that insofar as we have to live with nuclear power, we ourselves become increasingly well policed.[144]

In Europe, where population densities are high and terrorist attacks are now common, the choices are particularly stark. A West German government-sponsored study examined the societal implications of a large-scale nuclear power system and found that the security measures would make much of West Germany a police state, requiring a curb on states' rights, a suspension of some civil liberties, and per-

haps even a change in the constitution. Critics point to the Wackersdorf nuclear reprocessing center, now under construction, which has already been heavily militarized to deter demonstrators. Local people find unpleasant reminders of their country's past as they walk around the heavily fortified site, guarded by police armed with water cannons, attack dogs, and helicopters. If Wackersdorf is ever completed, roads and rail lines to the site will need similar protection since they will carry thousands of tons of deadly spent fuel.[145]

Heavy reliance on nuclear power also poses economic risks that other energy sources do not entail. Considering the outcry that an accident in the Ukraine caused in Western Europe, it is quite likely that a major accident in the West would create irresistable pressure to shut down all nuclear plants of a similar type and perhaps all others as well. In France, where two-thirds of the nation's electricity now comes from nuclear power, such a move could well stagger the economy. Making an entire nation dependent on such a vulnerable technology is a victory of dreams over pragmatism. Even if nuclear power could be justified on economic, safety, and environmental grounds, using it to supply more than one-third of a country's electricity is a fool's wager.

A growing number of people are asking where the nuclear path is leading. Each individual nuclear plant is justified by authorities on short-term economic grounds, but it is unclear whether leaders have a coherent vision of the kind of society their incremental decisions are creating. Nuclear power has increasingly become a program looking for a justification. In the sixties, it was viewed as a logical next step in energy technology since it was based on the latest scientific breakthroughs, a rationalization that now seems insufficient and naive. In the mid-seventies nuclear power was justified as a way of reducing oil dependence. This did in fact happen in some countries, but today relatively little oil is used for power generation; new nuclear plants are mainly displacing coal.[146]

In the late seventies and early eighties nuclear power was promoted as cheaper than coal-fired power, an argument that has fallen victim to nuclear cost overruns and falling coal prices. Then in the mid-eighties, as the economic argument faltered, nuclear proponents,

"The list of promising alternatives to both coal and nuclear power includes industrial cogeneration and a range of small-scale alternative generating technologies."

including the secretary general of the IAEA, converted to environmentalism and argued that threats of acid rain and carbon dioxide-caused climate change made nuclear power essential. This argument quickly created enemies in the U.S. utility industry which is trying to avoid acid rain legislation as well as fighting for financial breaks for its troubled nuclear plants. These environmental problems are critical ones, but using nuclear technology to solve them is like proposing an extraterrestrial migration program to solve the world's population problems. A transition to nuclear power cannot be accomplished quickly enough to make a difference, and its cost could well bankrupt the world economy.[147]

It is hard to rationalize spending hundreds of billions of dollars on an industry that will supply less that 15 percent of the world's power and 5 percent of its energy in the year 2000.[148] Still, there are some basic questions that societies must answer: Can we run a growing world economy on energy sources other than nuclear power, and what will it cost? Dozens of reports have attempted to address these questions, and they go well beyond the scope of this paper. However, one central conclusion stands out: Nuclear power in anything resembling its current form does not even address the world's most pressing energy problems.

First, the world is rapidly running short of liquid fuels to run automobiles, but nuclear power can provide little help here, even if most of its problems are resolved. Nuclear-powered electric cars would be inconceivably expensive. Second, developing countries have the greatest need for expanded energy supplies. Although the IAEA and other organizations have aggressively promoted nuclear power as a boon to the Third World, it is hard to imagine that their "experts" have spent much time in developing countries. The Third World's nuclear experience can best be described as an economic tragedy. Because of the huge infrastructure investments required, nuclear power has essentially no chance of meeting the energy needs of dispersed rural populations in the forseeable future.[149]

The list of promising alternatives to both coal and nuclear power is much longer and more thoroughly researched today than it ever was

in the past, thanks to the energy research programs begun in the seventies. These alternatives include industrial cogeneration plants run on coal, natural gas, or biomass, and a range of small-scale alternative generating technologies such as wind power, geothermal energy, hydropower, and photovoltaics. Also important is the potential to use electricity efficiently, allowing half as many power plants to meet the same level of needs.[150]

In parts of the United States where institutional reforms and incentives have been implemented, these alternatives are developing rapidly and planners are confronting an excess rather than a shortage of electricity. In the country as a whole, an estimated 7,000 to 8,000 megawatts of new generating capacity from small-scale alternatives will be added annually in the next few years. These additions are equivalent to the peak nuclear additions of the mid-eighties and will provide the country with enough additional generating capacity to avoid building central power plants for the rest of the century.[151]

The world's energy problems have no easy solutions—a fact that will remain true regardless of whether nuclear power is abandoned. However, a recent global study by scientists in four countries describes in detail one path beyond fossil fuels that relies heavily on energy efficiency and renewable energy sources to keep global energy requirements from rising substantially above their current level. The transition is clearly possible, but it will require decades of research, huge investments, and difficult institutional reforms. One benefit of a deliberate decision to abandon nuclear power would be the added incentive to invest in realistic alternatives. Already, West Germany, Greece, and other countries have reinvigorated their alternative energy programs as a direct consequence of Chernobyl.[152]

Nuclear power is advocated and objected to for dozens of reasons, and the rationales on both sides often make sense when viewed in isolation. But the ultimate decision should be based on society's wider vision of its future. Chernobyl's lasting legacy may be that it has put such issues squarely on the table—despite the misgivings of nuclear power supporters. Governments and societies may begin taking a more deliberate role in shaping their technological futures.

A growing number of countries are likely to opt for the deliberate, planned phaseout of nuclear power. Those that do not may believe they are gaining important technological advantages, but more likely they will be preoccupied with divisive struggles that could weaken them politically as well as economically. George Woodwell, a biologist who heads the Woods Hole Research Center in Massachusetts has described the current choices well:

> It seems clear that we have given nuclear power a fair trial and that its promise falls far short of even the most modest hopes. The earth is not large enough to accommodate this technology; political systems cannot manage it; and although scientists and technologists may have performed admirably, they have not been able to solve the fundamental problems of contamination of an imperfectly run world. The verdict is the same even if we consider economic problems, climatic changes due to carbon dioxide increases caused by fossil fuels, and the apparent pressures on global energy supplies. These problems can be resolved without nuclear power—and will be, if there is to be a future for industrial civilizations. Nuclear power can be systematically and deliberately abandoned as a potential source of power.[153]

Chernobyl was an event of major historical proportions that later generations will undoubtedly mark as a milestone of the twentieth century. Its real importance lies not in the actual accident but in the fact that it has triggered international political recognition of the economic and human tragedy that nuclear power threatens to become. The global nuclear endeavor simply is not working, and a deliberate decision to abandon nuclear power and accelerate the development of alternatives would be a victory of pragmatism.

A move away from nuclear power would also be an important step in placing human controls on technology. In the past, people have employed whatever the world's laboratories produced. But in recent years, a growing number of technologies have been rejected, including chemicals that turned out to be carcinogenic and supersonic passenger planes that proved uneconomic. Chernobyl's sharply articu-

lated message is that nuclear power is a technology unsuited to human fallibility and open political institutions. The deliberate and planned abandonment of nuclear power would not indicate humanity's decline, but rather its advancement.

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